URANIUM MINING ON THE COLORADO PLATEAU

BY W. L. DARE, R. A. LINDBLOM, AND J. H. SOULE

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W. L. Dare,[1] R. A. Lindblom,[2] and J. H. Soulé[1]

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INTRODUCTION

This circular is the first of a series of publications describing uranium mining on the Colorado Plateau. Later circulars are planned in which exploration, development, and mining methods and costs will be described after a detailed study of various operations.

Because of the introductory character of this paper, those well-publicized phases of the industry such as geography, history, prospecting, and exploration are described but briefly. Primarily, attention has been devoted to the general problems that are encountered in mining ore bodies and to the factors that affect the selection of development and mining methods. Those familiar with mining may class the information contained in this paper as elementary; however, its inclusion is considered necessary for the completeness of the series of papers. It will also serve as a source of information for people who are interested in uranium but are unfamiliar with mining.

DESCRIPTION OF THE COLORADO PLATEAU

The Colorado Plateau covers an area of over 100,000 square miles and is roughly centered around the common corner of Arizona, Colorado, New Mexico, and Utah, as shown in figure 1.

The whole plateau is an area of high elevation ranging in most parts from 5,000 to 11,000 feet above sea level. It consists of many smaller individually cliff bordered plateaus and mesas, highly dissected canyon-lands, sage-covered plains, and large expanses of desert. It is marked by a number of laccolithic mountains and volcanic cones and plugs, which rise as high as 13,000 feet. The Colorado Plateau is characterized by more or less horizontally bedded sediments in contrast to the mountain masses of tilted sediments and igneous rocks on the west, east, and south (see figs. 2 and 3).

Climatic variations are great owing to the extensive size and extreme relief of the plateau. Summers are hot in the lower altitudes and pleasant in the higher areas. Freezing temperatures are common in the winter, and periods of severe cold weather may be long. The climate is arid to semiarid with an annual precipitation of about 6 inches in the southern part of the plateau and about 10 inches in the

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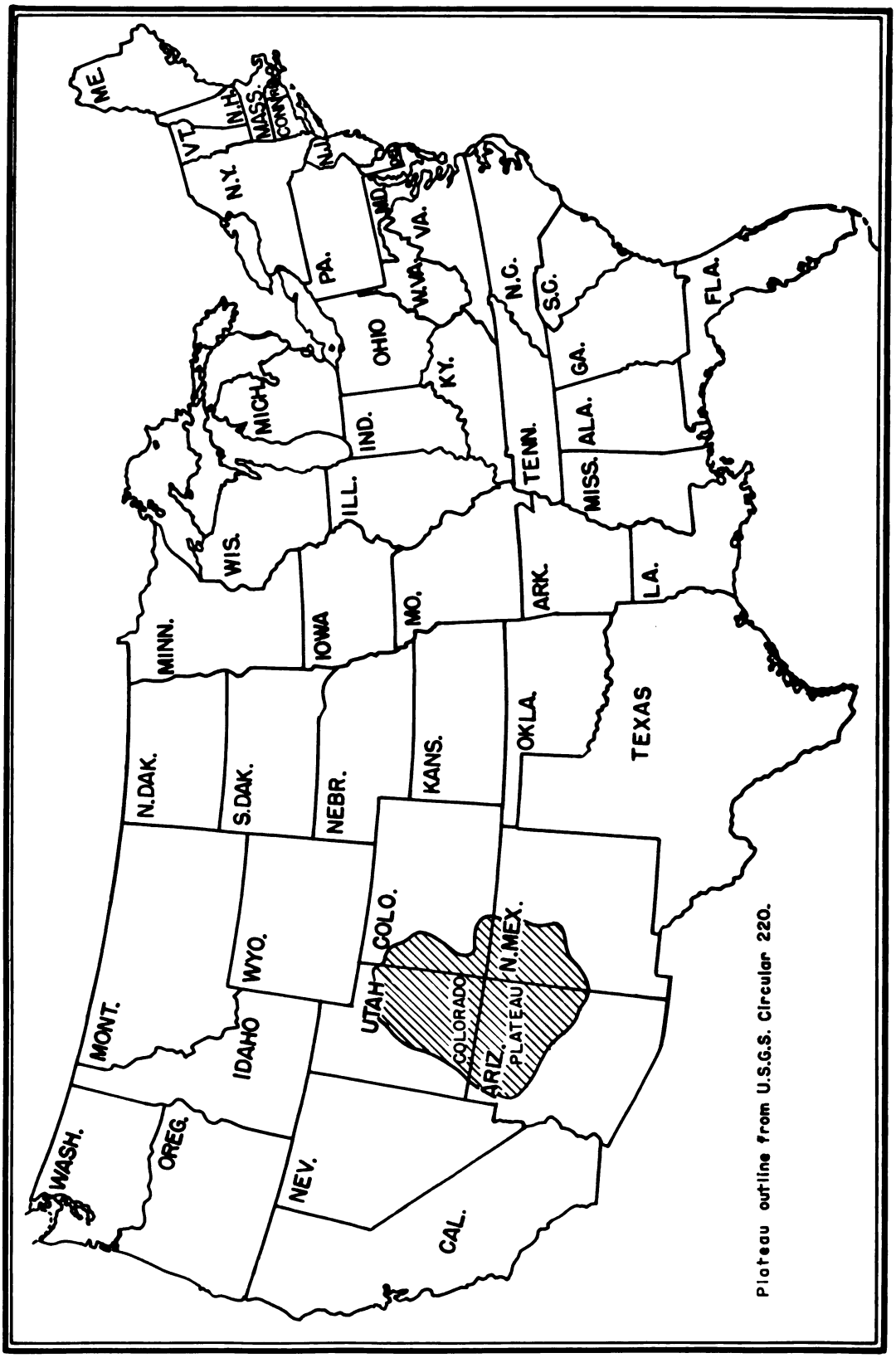

Figure 1. - Location map of Colorado Plateau.

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Figure 2. - General View looking northwest from Club Mesa, Montrose County, Colo., toward the La Sal Mountains, Utah.

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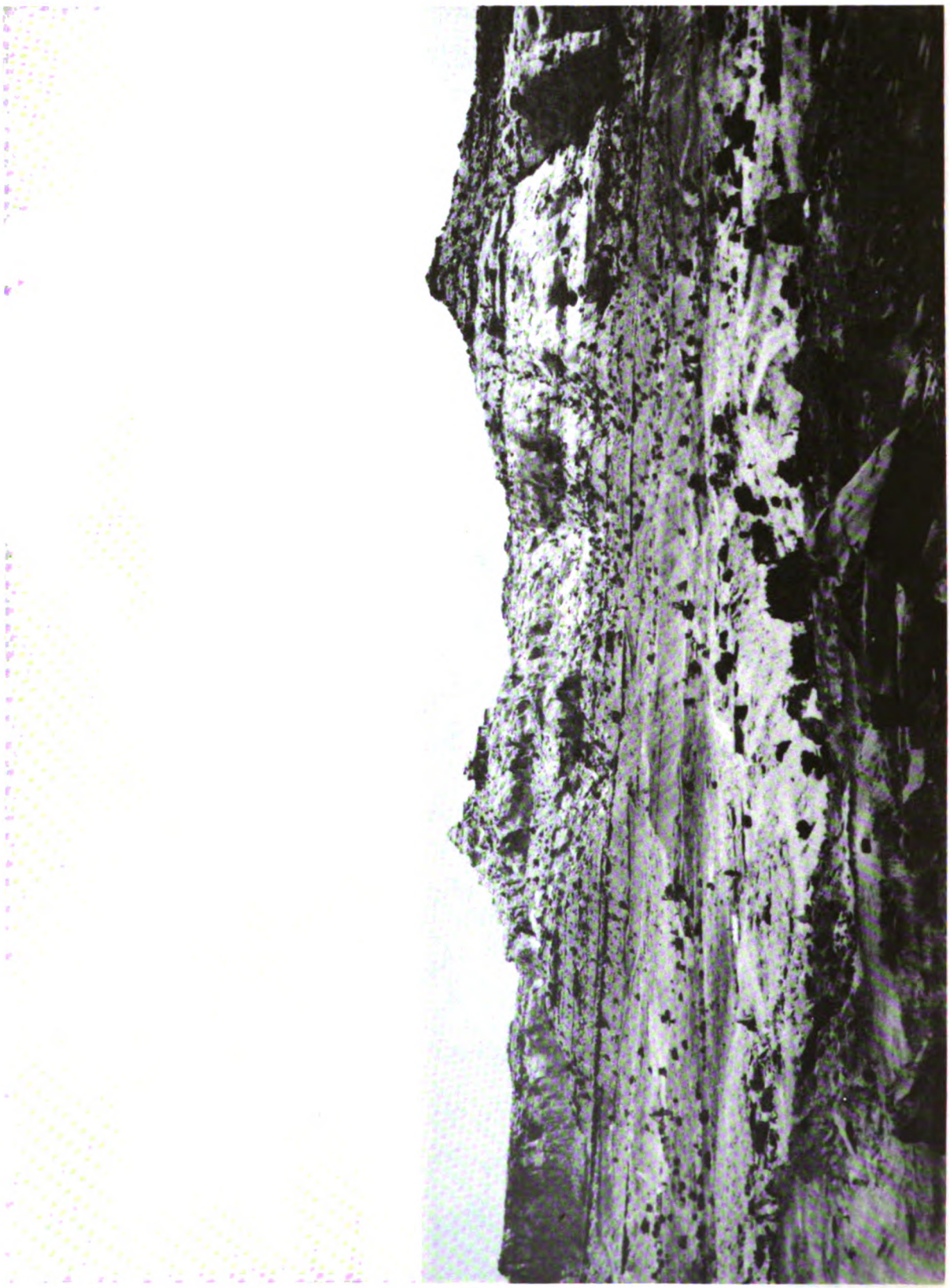

Figure 3. - View looking east, Temple Mountain district, Emery County, Utah.

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northern part. Forests of yellow pine occur in the higher elevations where precipitation is heavier. The land at lower elevations is covered in places by pinon and juniper, and in large areas the vegetation is limited to sage, bunch grass, and associated growth.

The Colorado River and its tributaries drain the larger part of the plateau. There are relatively few perennial streams, and water must be hauled considerable distances for many of the mining operations. Flash floods are a common summer hazard in the narrow canyons and washes.

The region is sparsely settled and contains some of the most isolated areas in the United States. Roads within the region are comparatively poor, although considerable progress in road construction has been made during the past few years. The Atomic Energy Commission under their access-road program, had constructed or improved over 900 miles of truck roads at a cost of over $5,000,000 by June 30, 1954. Although there are no accurate estimates available, private industry has built many miles of jeep trails and considerable mileage of improved roads that meet the standards for heavy haulage. Many of the mines are reached by unimproved roads that become impassable after heavy rains or during periods of melting snow. Four-wheel drive Jeeps and low-geared pickups are most favored for off-highway use.

Grand Junction, Colo., is the largest city on the plateau and has a population of approximately 25,000 in its metropolitan area. Mining supplies of all kinds can be obtained here and to a lesser extent in several small centers. Denver, Colo., and Salt Lake City, Utah, are the major supply centers east and west of the plateau. Uranium processing plants and ore-buying stations are strategically located on the plateau and outlying areas. It is the Commission's policy to arrange for construction of additional buying stations in areas where production potential justifies the need. Ore haulage from mine to buying point in the major producing districts seldom exceeds 100 miles. The Commission will consider making special marketing arrangements when producing mines are in more remote areas. Figure 4 shows the present ore-processing plants and ore-buying stations on the plateau and outlying areas.

GEOLOGY

The Colorado Plateau consists, in general, of a series of sedimentary rocks ranging from 5,000 to 20,000 feet thick. Most of these rocks were deposited during the interval from late Paleozoic through early Cenozoic time in essentially a horizontal sequence. A generalized stratigraphic column of the central plateau area is shown in figure 5. Regional deformation of this blanket of sediments began about the end of Cretaceous time and continued intermittently throughout the Tertiary period.

The sediments are predominantly sandstones and mudstones. The sandstones are red, brown, and buff and of varied composition. Some have characteristics of marine sedimentation, but most are continental deposits of fluviatile and aeolian origin. The mudstones differ greatly in color. Limestones and conglomerates are present in minor amounts.

These beds are horizontal or slightly tilted, except where disturbed by anticlinal and monoclinal folds, high-angled faults, igneous intrusions, and salt anticlines. Laccolithic intrusions occurred during Tertiary time and are now exemplified by the La Sal, Henry, and other mountain ranges.

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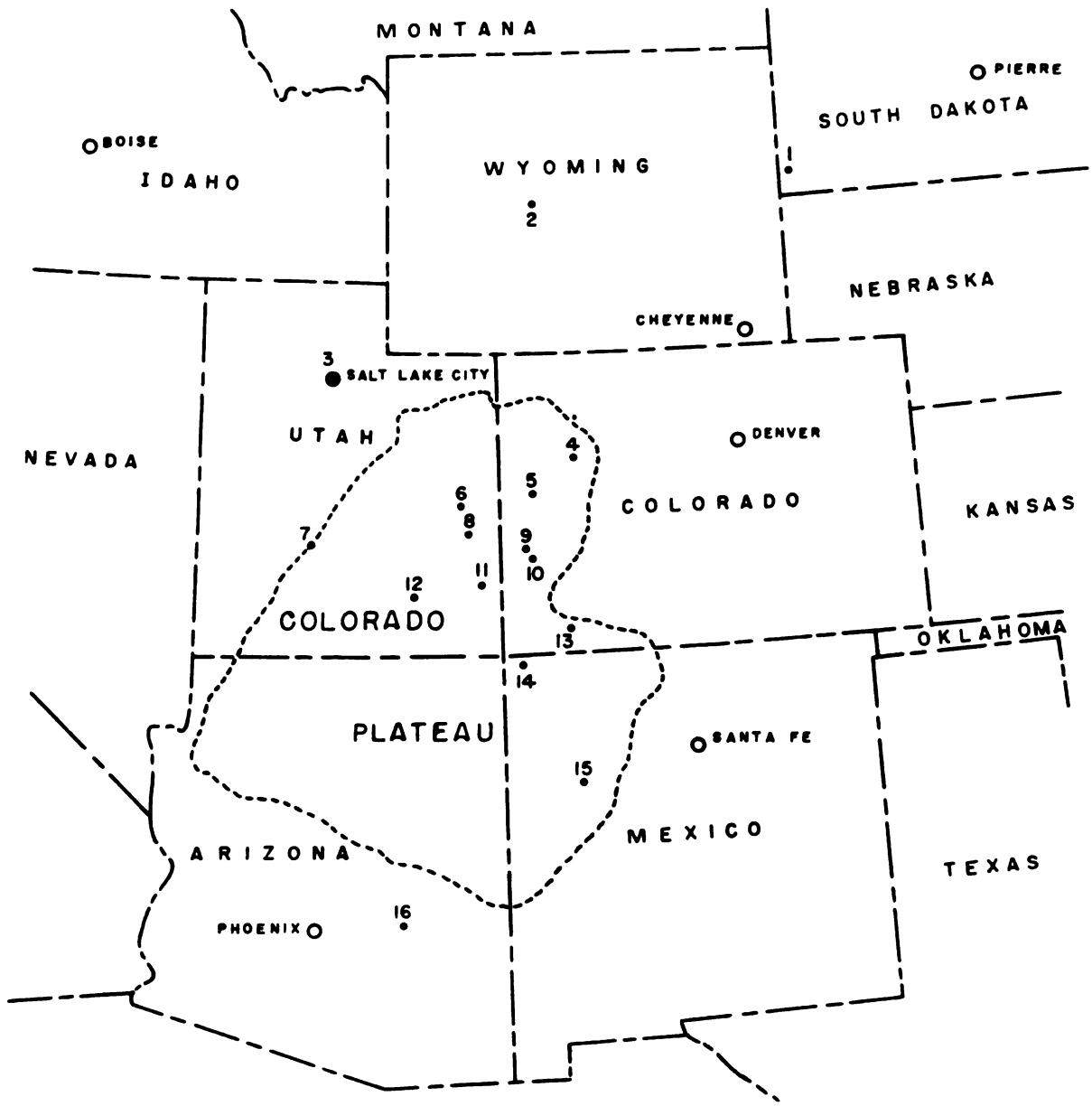

EXPLANATION

1. EDGEMONT, SO. DAKOTA – BUYING STATION.
2. RIVERTON, WYO. – BUYING STATION.
3. SALT LAKE CITY, UTAH – MILL AND BUYING STATION.
4. RIFLE, COLO. – MILL AND BUYING STATION.
5. GRAND JUNCTION, COLO. – MILL AND BUYING STATION.
6. THOMPSON, UTAH – BUYING STATION.
7. MARYSVALE, UTAH – BUYING STATION.
8. MOAB, UTAH – BUYING STATION
9. URAVAN, COLO. – MILL AND BUYING STATION.
10. NATURITA, COLO. – MILL AND BUYING STATION.
11. MONTICELLO, UTAH – MILL AND BUYING STATION.
12. WHITE CANYON, UTAH – BUYING STATION.
13. DURANGO, COLO. – MILL AND BUYING STATION.
14. SHIPROCK, N. MEX. – MILL AND BUYING STATION.
15. BLUEWATER, N. MEX. – MILL AND BUYING STATION.
16. GLOBE (CUTTER), ARIZ. – BUYING STATION.

Figure 4. - Location map of uranium mills and ore-buying stations on the Colorado Plateau and outlying areas.

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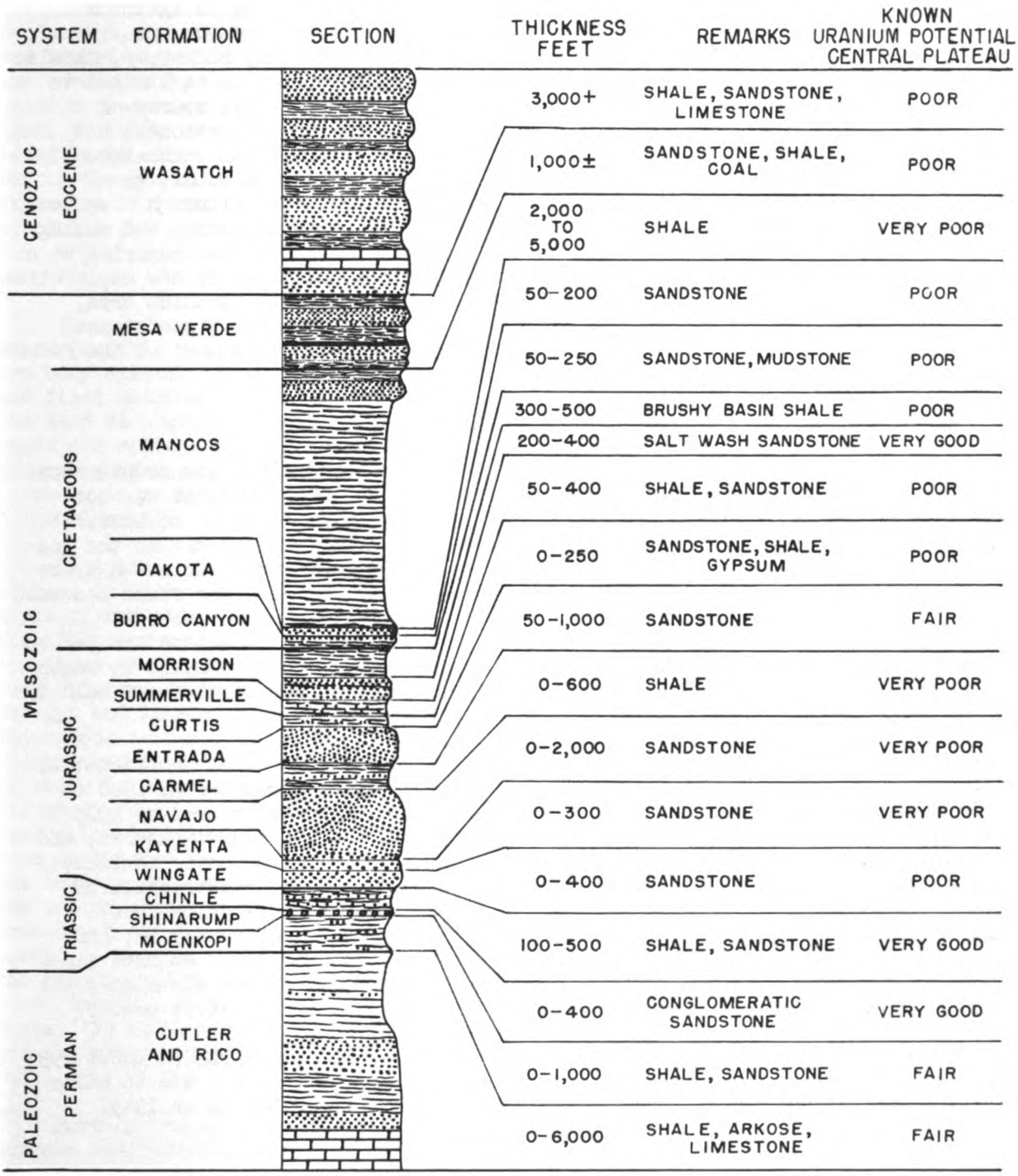

BASIC DATA FROM A.E.C. INFORMATION.

Figure 5. - Generalized stratigraphic column, central plateau area on Colorado Plateau and outlying areas.

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Uranium ores have been mined from some 20 formations ranging in age from Hermosa (Pennsylvanian) to Bidahochi (Pliocene). Most of the uranium ore production from the Colorado Plateau has come from the Morrison, Shinarump, Chinle, and Todilto formations. Ore production from the Todilto formation is limited to the Grants area in New Mexico. Sandstones have been the principal source of uranium ores, but production has also come from conglomerates, limestones, and mudstones. Uranium minerals are usually found in association with carbonaceous material in the sediments. The ore bodies occur in irregular, tabular, or lens-shaped masses, and, in general, they parallel the bedding, although they do not follow the bedding in detail. Until recently, uranium prospecting and mining were confined to carnotite and other vividly colored, secondary ores occuring at or near the surface. Deeper mining and an intensified search, aided by new exploration techniques, has resulted in the discovery of many other types of uranium ores, including copper-uranium sandstones, uraninite-and vanadium-bearing sandstones, uraninite-bearing limestones, and others. It is anticipated that most of the future production of uranium will come from unoxidized-type ores.

HISTORY OF URANIUM MINING

Carnotite-type ores were probably first mined by Indians for use as pigments. Although the early settlers undoubtedly knew of the yellow mineral, it was not mentioned in available literature until 1881, when a prospector sent to Leadville, Colo., for assay, some "yellowish mineral" which he mined from a shaft in the Roc Creek area of the present Uravan mining district, Montrose County, Colo. A trace of gold and silver was found and the claim was later abandoned. The first recorded production was in 1898, when 10 tons of carnotite ore averaging 20 percent U_3O_8 and 15 percent V_2O_5 was shipped from the same area. The ore was sacked and packed on burros 12 miles to Paradox Valley; from there it was shipped 80 miles by wagon to Placerville, Colo., and then to Denver by rail where it was sampled and sold for $2,600.00 to French scientists for delivery to France.3 4/

The discovery of radium by the Curies in 1898 created a market for carnotite ores. Several small plants were constructed in the plateau area around 1900 to extract uranium and vanadium oxides. Uranium deposits were discovered by 1905 in what today are the Uravan, Slick Rock, Thompsons, San Rafael, Henry Mountain, and other mining districts. Small-scale mining of high-grade rim deposits continued, and both high-grade ore and concentrates were shipped abroad for extraction of radium. Although World War I disrupted the European market for radium ores, additional domestic plants were constructed primarily to extract vanadium, and mining of carnotite-type ores continued unabated until about 1922. At this time, the decreased need for vanadium and cheaper radium extraction from the high-grade ores of the Belgian Congo broke the domestic market for carnotite-type ores.5/

There was a limited production of carnotite-type ores from 1923 to about 1935 when these ores were again in demand for their vanadium content for use in alloy steels. This second period continued until the end of World War II in 1945.

3/ Coffen, R. C., Radium, Uranium, and Vanadium Deposits of Southwestern Colorado: Bull. 16, Colorado Geol. Survey, 1921, 231 pp.

4/ Letter of George Kimball, Discovery of Carnotite: Eng. Min. Jour., vol. 77, 1904, p. 956

5/ See work cited in footnote 3.

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The Atomic Energy Act of 1946 provided a program for Government control of the production, ownership, and use of fissionable material to promote the common defense and security. With the establishment of the Atomic Energy Commission to administer the development, use, and control of atomic energy, the third period of mining uranium ores began. The first price schedule for uranium ores became effective on April 9, 1948. Prices have been revised upwards several times and the present schedule provides a guaranteed minimum price effective through March 31, 1962. During the past few years, production has doubled and redoubled, and even greater expansion is anticipated. Figures 6 and 7 show Atomic Energy Commission price schedules for uranium ores.

PROSPECTING AND EXPLORATION

Prospecting for uranium is the search for uranium minerals or indications of their possible existence. Exploration is the work done to determine if a uranium ore body exists. Early prospecting consisted of visual examination of outcrops and float material. The characteristic color and appearance of the oxidized ores was used as a guide. Later, development of radiation-measuring devices provided a rapid and efficient means of determining the presence of uranium minerals. The assured market provided by the Government's uranium program has led to a tremendous increase in prospecting and exploration for unknown or undeveloped sources of this critical metal.

Radiation detection instruments enable the operator to detect the presence of uranium in rocks having little or no visible indications of uranium minerals. Two types of radiation counters are in general use--the Geiger counter and the scintillation counter. Geiger counters are generally cheaper and usually less sensitive than scintillation counters but are satisfactory for most uses. Scintillation counters are particularily adaptable for use in airborne radiometric surveys and in moving vehicles. There are certain principles that must be understood in using any radiation counter. A working knowledge of such factors as "background count", "equilibrium", "mass effect", and "cover effect" are necessary in order to use these instruments correctly. Samples should be taken of any new discovery for chemical analyses, especially in a new area, to confirm radiation indications that may be detected by counters. Counters can be calibrated and with some experience used to estimate the percentage of uranium oxide in ores for which the equilibrium state has been established. Two good references on prospecting and use of counters are "Prospecting for Uranium," by the U. S. Atomic Energy Commission and the Federal Geological Survey, and "Prospecting With a Counter," by Robert J. Wright, Atomic Energy Commission.6/ These booklets are obtainable from the Superintendent of Documents, Washington 25, D. C., for 55 cents and 30 cents, respectively. A volume entitled "Handbook for Prospectors and Operators of Small Mines," by M. W. von Bernewitz and H. C. Chellson,7/ contains information of a general nature with which anyone considering a prospecting venture should be familiar.

Most of the ore deposits now being mined on the Plateau were discovered from surface indications. Owing to the intensive prospecting of the surface in this

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6/ United States Atomic Energy Commission and the United States Geological Survey, Prospecting for Uranium: Rev. 1951, 128 pp.
Wright, R. J., Prospecting With a Counter: United States Atomic Energy Commission RME-4028, 1953, 70 pp.

7/ von Bernewitz, M. W., and Chellson, H. C., Handbook for Prospectors and Operators of Small Mines: McGraw Hill Book Co., Inc., N. Y., 4th ed., 1943, 372 pp.

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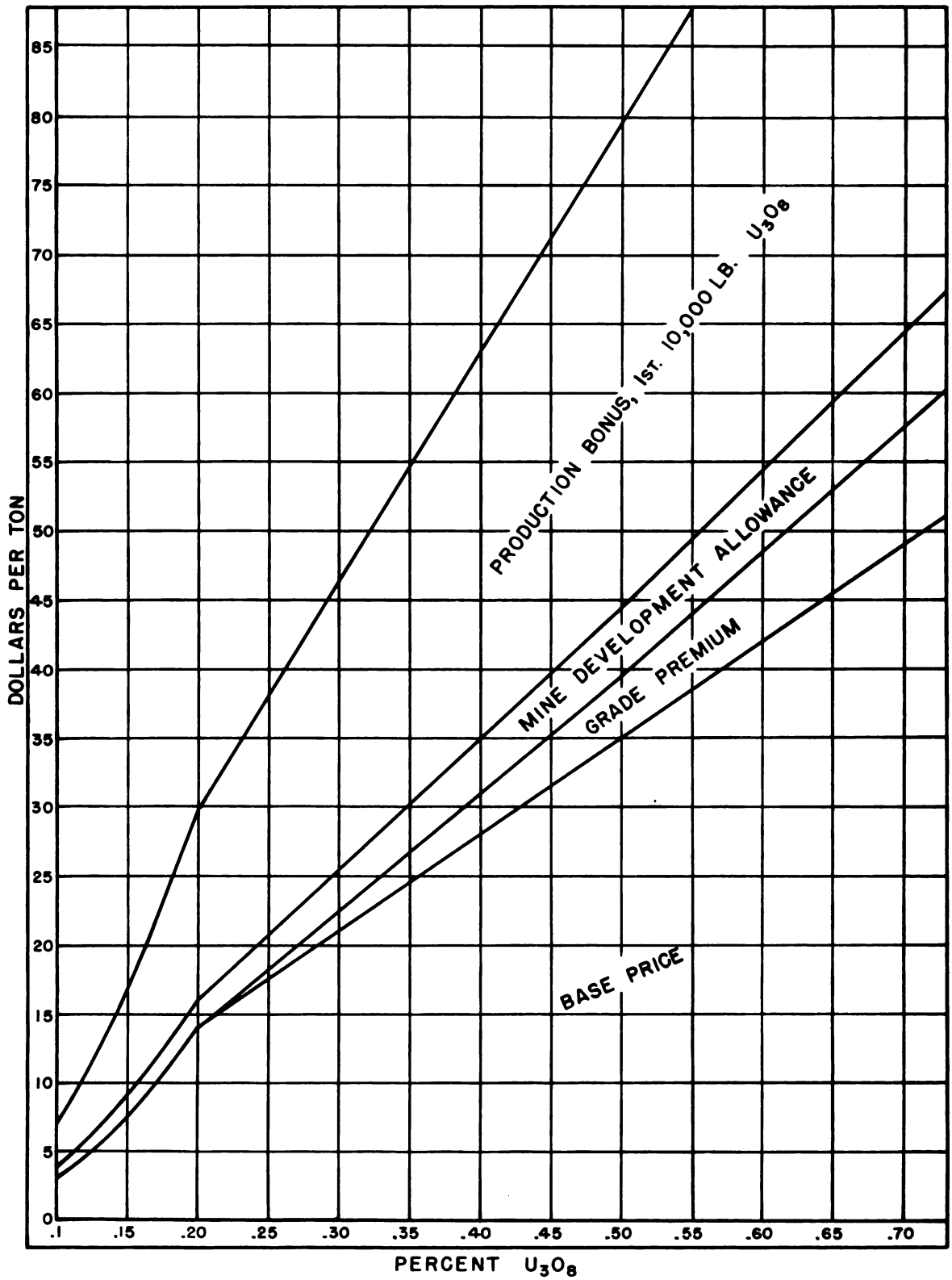

Figure 6. - Uranium price schedule, ores from 0.1 to 0.73 percent U_3O_8.

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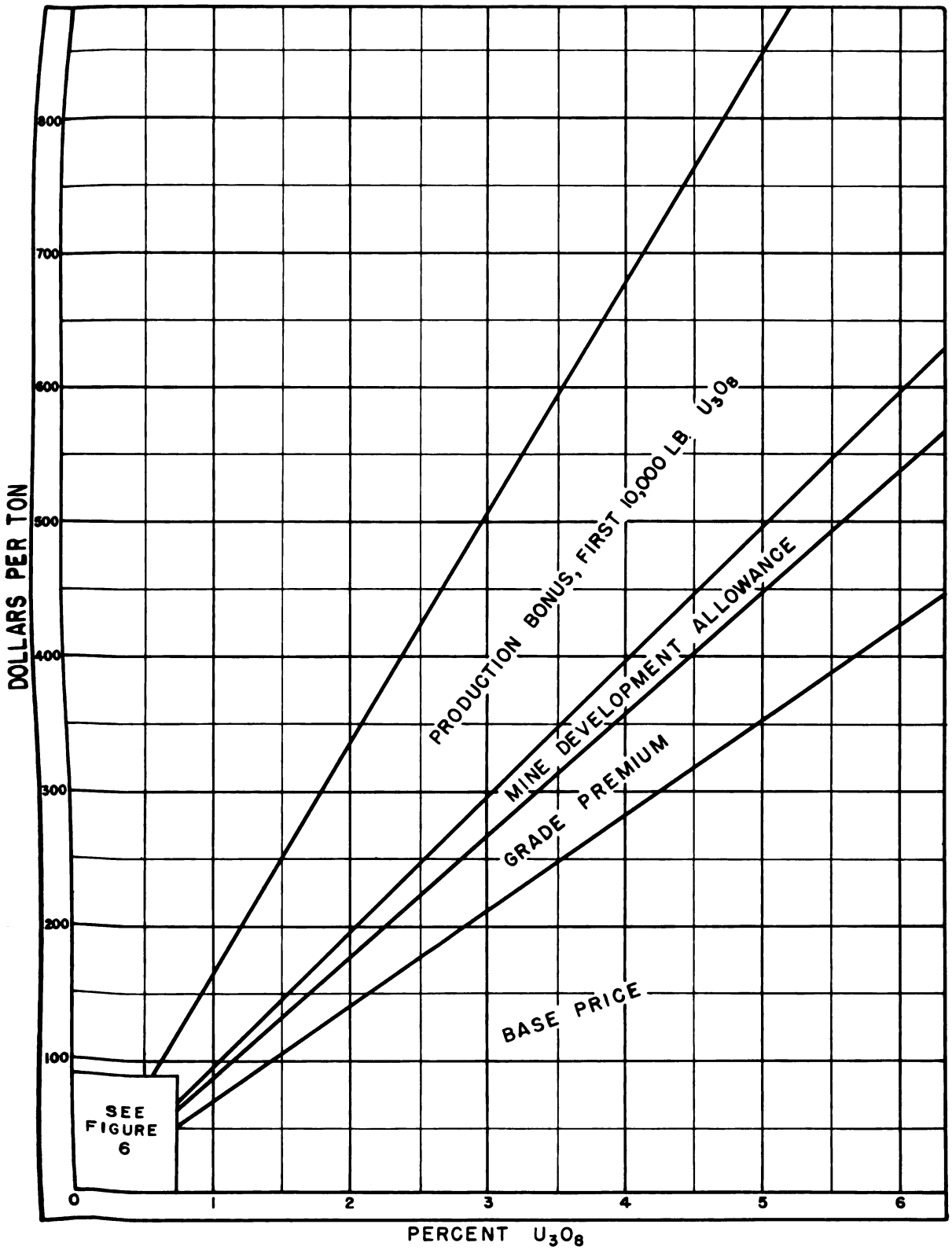

Figure 7. - Uranium price schedule, ores from 0.73 to 6.3 percent U_3O_8

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area, it is logical to assume that most future discoveries will be farther from rim exposures and at greater depths. Some experimental work has been done in applying geophysical methods, but to date drilling remains the most feasible method of exploring for unexposed deposits.

The validity of ownership of mining rights is important when contemplating any prospecting or exploration program. Mining rights can be obtained by locating mining claims on vacant and unappropriated public lands in the public land States in compliance with the Federal and State mining laws. Whether any particular tract of Federal land is open for prospecting and location under the mining laws can be determined by consulting the records of the appropriate District Land Office, Bureau of Land Management, and those of the County Recorder. The publication, "Mineral Patents, Information Relative to the Procedure for Obtaining Patent to a Mining Claim," by the Bureau of Land Management, Department of the Interior, 1950, lists the field office locations of the Bureau. Privately owned lands and minerals are not open to location of mining claims and arrangements for prospecting thereon or extracting ores therefrom must be made with the owner. Information as to the ownership of mineral rights on privately owned lands may be obtained by checking the records of the County Recorder. Information on the United States mining laws may be obtained from the Bureau of Land Management, Department of the Interior,8 9/ and information on the mining laws of the States may be obtained from the appropriate State office.

Anyone contemplating exploratory drilling should become familiar with the general literature on the geology of uranium deposits. There is much printed information available relating to ore guides and ore controls in the productive formations on the plateau. Generally accepted features that are favorable for uranium occurrence in sandstone formations are (1) fluvial origin of the formations, (2) alteration of the sandstones and associated mudstones from red to lighter shades, (3) presence of carbonaceous material, (4) interbedding of mudstones in the sandstones, and (5) to some extent, the thickness of sandstones.10 11/ Paleo stream channels, faults, unusual jointing, nearby intrusives, and anticlinal and other folding are structural features that possibly control uranium deposition.

The size, depth, and probability of occurrence of ore bodies characteristic of a specific formation in a given area determines the amount of risk capital that may be spent and the attendant amount of footage that may be drilled in a particular area with a reasonable chance of success.

Exploratory drilling may be divided into three phases, seeking geologic information, searching for ore bodies, and defining the physical characteristics of ore bodies. The divisions of the phases are not always well defined and two or all phases may be accomplished at one time or any phase may be eliminated. There are

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8/ Bureau of Land Management, Lode and Placer Mining Regulations: Circular 1785, rev. 1951, 19 pp. Contains the Federal mining regulations promulgated by the Department of the Interior.

9/ Bureau of Land Management, Information in Regard to Mining Claims on the Public Domain: Circular 1278, 4 pp. Briefly lists pertinent information to the location and purchase of mining claims under United States mining laws.

10/ Weir, D. B., Geologic Guides to Prospecting for Carnotite Deposits on Colorado Plateau: Geol. Survey Bull. 988-B, 1952, pp. 15-27.

11/ Wright, R. J., Ore Controls in Sandstone Uranium Deposits of the Colorado Plateau: Econ. Geol., vol. 50, No. 2, March-April 1955, pp. 135-154.

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no definite rules to be followed as each drilling program presents its own individual problems. However, as exploration progresses deeper, the value of this approach becomes increasingly important.

Drilling for geologic information is the first logical step in a relatively unexplored area where geologic data are lacking but a productive ore horizon is believed to be present or structural controls possibly exist. Drill holes may be spaced as much as 1,000 feet apart, or more under certain conditions. Core drilling will provide the most information. It is often possible to reject much of the area from further consideration by a study of the drill cores and radiometric logs of the holes and to then concentrate on those areas that are considered geologically favorable. Competent technical assistance is invaluable for proper planning and interpretation of results.

The second phase of exploratory drilling can be outlined when geologically favorable areas have been established. These holes are often drilled on a 50- to 200-foot grid pattern. Hole spacing may depend on the probable size of ore bodies peculiar to the target strata in the area being drilled, or may depend on the minimum size of a deposit that must be found to assure a profitable operation. Both resolve economically into the problem of determining the most effective method of exploring a given area for the least cost. The drill-hole pattern in the first case depends upon geologic conditions assumed to exist, so that theoretically one hole will penetrate any significant ore body or area of mineralization. This basis for spacing drill holes is commonly used when exploring for relatively small ore bodies at shallow depths. In the second case, drill-hole spacing depends more upon the economics of exploration, development, and mining. It is more applicable to deep deposits where the cost of development and mining, as well as the cost of deep drilling, must be carefully considered when laying out a grid pattern. Here, a rough estimate can be made of the cost of developing a deposit at the depth determined in the first drilling phase, and with the estimated cost of the required drilling program plus the estimated mining cost, the minimum size of an ore body that can be profitably mined at that depth can be determined. Structural controls and topographic features may locally affect hole spacing.

If ore is found in the second phase, closer spaced or off-set drilling may be necessary to obtain information as to size, shape, position, and other characteristics of the ore body. This information is important to establish the tonnage and value of a deposit and is essential for planning mine development. This additional drilling may have particular advantages when an ore body approaches marginal value, and the information gained may well compensate for the extra cost. In such case, additional drilling may sufficiently increase the ore reserves and thereby assure profitable mining, or conversely, the ore reserves may be sufficiently decreased to definitely exclude it from further consideration.

Careful planning of off-set drill-hole locations is stressed, especially for deep ore bodies, so as to get as much information as possible for the least cost. When surface drilling has established the general depositional trends of a deep ore body and indicates sufficient tonnage and grade to warrant development, it may be more economical to define its detailed physical characteristics by underground exploratory drilling as mining progresses rather than by additional and costly surface drilling.

The four general types of drilling used are churn drilling, diamond drilling, pneumatic-percussion drilling, and rotary drilling. There are many drilling contractors operating in the plateau area, and drilling costs vary with the type of

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drilling, depth of holes, and contracted footage. Construction of drill-rig roads for access to the proposed drill hole locations is usually the responsibility of the claim owner, though some agreements specify this work as part of the contractor's duties. Average costs for various types of drilling in the plateau area are tabulated on page 16.

Churn drilling has been used very little for exploration on the plateau. This is a relatively inexpensive method of exploration, and drilling to great depths is possible. In areas where overburden and underlying formations are loosely consolidated, the cable tool drill can perform better than any other type of drill. Sampling techniques are awkward, and the samples are bulky and need considerable handling. The material obtained as samples may not be representative when penetrating relatively thin ore beds. The relatively large amount of water required is also a disadvantage of this type drilling. Churn drilling has been used as an auxiliary to diamond core drilling to penetrate the upper formation when loosely consolidated or blocky. Churn drilling is adaptable where the relatively large holes can be used for mine ventilation, escape ways, and for the entry of pipelines and electric cables.

Diamond-core drilling is used extensively on the plateau. This is the most expensive method of drilling, but the valuable geologic data gained from cores is important in preliminary work. Correlation of detailed geology gained from cores permits intelligent study of an area being explored. Core drilling is considered necessary in the evaluation of deeper ore deposits where development costs become increasingly greater. Ore evaluations based on electronic logging devices are as yet not considered safe procedure without substantiating chemical analyses of cores from preliminary drill holes. Logging core holes with electronic equipment permits standardizing the instrument for later use in logging noncore holes in the same area. After the geology in an area has been established by preliminary reconnaissance core drilling, the average unit drilling cost can be decreased by plug-bit drilling to a depth near the target formation and coring only the target formation. Modern truck-mounted diamond-core-drills are very mobile and can drill relatively deep holes. Water, necessary for core drilling, is often scarce on the plateau. Air has been used to cool the bit and remove the cuttings with varying degrees of success. A diamond-core-drilling contract should stipulate a guaranteed percent core recovery.

Pneumatic percussion drilling is done either by light hand-held drills or heavy drills mounted as a wagon drill or on a truck, halftrack, or tractor. This drilling method is the cheapest when exploring for relatively shallow deposits. Typical costs range from $0.50 to $1.50 per foot. In dry formations percussion drilling is satisfactory to depths of 250 feet, and in exceptional cases percussion drilling has been done to depths of 400 feet. Percussion drilling in all but shallow holes is limited to dry formations as wet drilling has not proved successful. Cuttings, blown from the hole, are collected for samples of the material penetrated. A typical truck-mounted percussion drill is shown in figure 8. Development of heavier machines, more uniform large-hole steel, multipressured compressors, and improved bit designs have greatly improved pneumatic drilling techniques. Owing to lower bit cost, heavy percussion drills with extra heavy steel will far out-perform diamond drills and rotary drills in unusually hard formations such as the Dripping Springs quartzite and in hard easily fractured formations such as the Burro Canyon conglomerate. Percussion drills and sectional steel are also used in underground exploration. Long-hole drilling from existing mine openings permits cheap exploration for possible nearby ore bodies. Such holes are usually limited to a length of 100 feet, and many operators limit these holes

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Figure 8. - Exploratory drilling with truck-mounted pneumatic-percussion drill.

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to 50 feet. In this method a number of holes are fanned horizontally and vertically from the same drill setup.

Rotary drilling, originally developed for seismic work in oil exploration, is now common on the plateau. It is competitive cost wise to percussion drilling and is faster and capable of drilling to greater depths. The drill rigs are truck-mounted, and dry drilling usually is practiced, although wet drilling can be done (see fig. 9). This type of drill is best used where shallow drilling depths, 200 feet or less, predominate and where no core is required. For best results the ground must be fairly consolidated and the overburden shallow. When the ground is dry and not too hard this drill can out drill any other type. Drilling costs will increase where the overburden is thick and rocky. Hard rock drilling will result in excessive bit costs. For comparatively shallow holes average contract drilling prices range from $0.60 to $1.50 per foot. Drilling holes that exceed 200 to 300 feet are increasingly more expensive. If core is desired in sections of a hole it can be obtained with this type drill rig, but as the speed of drilling is slowed, costs increase.

TABLE 1.--Average contract drilling prices, Colorado Plateau area 12/

Depth of hole, feet	Type of drill, cost per foot				Percussion
	Diamond drill		Rotary		
	Core	Non-core	Wet	Dry	
0-100	1.75-2.50	1.00-1.75	1.25-1.75	0.40-1.00	0.50-0.75
100-200	1.85-2.75	1.50-2.25	1.25-1.75	1/ .60-1.25	1/ .75-1.00
200-300	2.75-3.50	2.00-2.75	1.50-2.50	1/1.25-2.00	1/1.25-2.00
300-400	3.00-4.00	2.50-3.00	1.50-2.50	1/1.25-2.00	1/2.00-3.00
400-500	3.50-5.50	3.00-4.00	2.00-3.00	1/2.00-3.00	
500-750	5.50-7.00	3.50-4.50	2.50-4.00	(2)	
750-1,000	7.50-9.00	4.50-6.00	4.00-5.00	(2)	

1/ Denotes holes not guaranteed to bottom if wet ground is encountered.
2/ Quotations below 500 feet not reliable owing to wet ground conditions.

When core drilling, the cores should be logged and checked radiometrically, and mineralized cores from within the ore zone should be assayed chemically. When noncore drilling, cuttings from the ore zone should be collected and saved for the same purpose. Probing drill holes with radiometric equipment is common practice in both cases.

It is important to estimate ore reserves accurately. For tonnage calculations, an ore body is assumed to be a uniformly tapered mass between drill holes, and a tonnage factor of 14 cubic feet per ton is commonly used. The average grade of ore cut by a single hole is the weighted average of all samples from that hole within the ore zone. If the holes are equally or near equally spaced, grade of ore reserves may be quickly calculated by applying equal areas of influence for each hole and using the weighted average of percent metals of all holes. Polygonal areas of influence or the method of triangular blocks is sometimes used where drill holes are irregularly spaced.

The selection of grade-thickness cut-off values requires considerable skill as each deposit has characteristics which affect the cut-off value. Various

12/ Sullivan, R. G., Drilling Techniques on the Colorado Plateau: Min. and Contract. Rev., vol. 56, No. 11, November 1954, pp. 6-8.

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Figure 9. - Rotary drill rig with 315 c.f.m. compressor mounted on second truck.

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grade-thickness cut-off values are used, depending on the estimated cost of development and unit cost of mining as well as relative conditions such as selectivity of mining and blending possibilities.

DEVELOPMENT

Development of an ore deposit is preparation for mining, either by underground or open-cut mining methods. Underground development is providing access to the ore body by an adit or shaft and preparing it for mining. Open-cut development consists of preparatory work and stripping so as to expose the ore.

The physical characteristics of the deposit, such as its depth, thickness, shape, tonnage, and grade, should be established with as much accuracy as possible before consideration is given to mine development methods. Estimated extraction costs, based on the cheapest method of development, compared to return in sales will determine if the deposit can be mined at a profit.

A few tons of uranium-bearing material found far from a rim and under thick overlying sediments, where development and mining costs will exceed the value of the deposit, obviously cannot be mined at a profit. Large, easily accessible deposits where the yield will be sufficient to make up for any weakness in development and mining methods can be classified as ore without detailed cost studies. However, the development method used for the latter type of deposit will be a factor in obtaining the maximum return on investment capital. The deposits that approach marginal value are of special interest, and particular attention should be given to the choice of development and mining methods, or variations in technique, that may permit extraction of the deposit at a profit.

Capital expenditures for mine development are the costs of underground or surface excavations to provide access to the ore. The expenditures necessary for access road construction, establishment of a camp, and installation of a mine plant must also be considered in selecting a development method because these costs will vary with the development method used. The costs of property acquisition and exploratory drilling are capital expenses of any mining company. However, the decision to mine a specific deposit will depend upon the net returns from the sale of ores and not upon the costs incurred before starting development work. Therefore, risk capital spent for property acquisition and exploratory drilling will not be considered as part of ore-extraction costs.

Rate of production is important in development planning. Primarily, the planned rate of production will depend upon the total tonnage of the ore body and its manner of occurrence. The optimum size of development layout should permit extraction of the estimated tonnage at the planned rate of production. It is as important not to overdevelop an ore body as it is not to underdevelop it. Average size development openings can adequately handle the daily production from most of the plateau uranium deposits.

The following factors should be considered in planning mine development:

1. Topography and depth to deposit.
2. Size, grade, attitude, and tonnage of deposit.
3. Planned rate of production.
4. Comparative costs of different applicable development methods.

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Underground Development

Ore bodies on the plateau may be generally classified as bedded deposits erratic in size, shape, attitude, and grade. Open stope mining is the basic underground method used with variations depending on the specific characteristics of the ore body. This basic mining method usually will not be affected by the development method. When determining if a deposit can be mined at a profit by underground methods, all costs necessary to place the ore in the surface bin should be estimated. If the actual direct cost of mining the ore is considered as constant, the problem is then related to those costs of reaching the ore body with the best type and size of entry necessary for the planned size of operation. Therefore, cost of underground development is a major factor in deciding if the deposit can be mined and is a factor in the return on investment capital.

Until recently, most plateau uranium deposits have been developed by adits. Initial ore discoveries were mineralized outcrops along rim exposures, and usually were mined by a system of horizontal or nearly horizontal workings developed from the rims. Development planning was not a problem, rather, it was a case of following the ore or ore leads. Later discoveries by exploratory drilling behind these early workings or behind other favorable rim exposures also were developed by adits or continuations of earlier workings. Because of lower cost, adit development lent itself to small operations near rims. Few of the rim exposures of known ore horizons within the plateau area remain unprospected. Some undeveloped deposits will be mined close to rim exposures, but it is logical to assume that most future discoveries will be in areas more distant from the rims. The problem of development will then become more complex. Choice of an underground development method will depend on the physical characteristics of the overlying formations, the ore body, and the topography.

Where a deposit has been found at a considerable depth, but relatively near as easily accessible rim, the choice of development by adit would be logical. Access to a deposit situated in a relatively flat-lying area at considerable distance from a rim would unquestionably be by a shaft. However, other deposits can be developed either by shaft or adit, and a choice will depend on the estimated costs of each.

Underground Development Methods

A mine opening, whether adit, inclined or vertical shaft, or slope-type entry, usually should be considered as permanent and should be planned for efficient use throughout the life of the mine. Considerations relative to the type and location of the mine opening are:

1. Topography
2. Center of deposit
3. Lowest point in the ore body
4. Condition of overburden and rock at site of opening
5. Use of existing workings
6. Property boundaries

Topography is the main factor in determining the type of entry, and it is important to take the utmost advantage of existing conditions. The mine opening should be situated to permit construction of a surface plant near the opening, which might consist of a headframe, hoist house, ore bins, shop, change house, and other mine buildings. The cost of constructing access roads to the mine opening also will

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depend largely on topography. Conditions may be such that the direct cost of underground development favors an adit but the high cost for construction of an access road and site for a surface plant, as well as the cost of road maintenance, will favor entry by shaft. An adit portal should be located at a point on the rim that permits contact with the ore body at the cheapest overall cost. A portal site at the point of least distance from the ore may not necessarily be the point of least cost if topographic conditions require high construction costs for an access road and a mine plant site. A vertical shaft sunk at the lowest surface elevation near the deposit or an inclined shaft sunk from a favorable surface slope will decrease distance to intersect ore. Also, an inclined shaft sunk from a hillside or slope may permit construction of ore bins at an elevation to permit easy skip or ore car dumping arrangements without need of a trestle or waste slope. Care should be taken to locate the mine opening above the bottom of gullies or canyons to insure against flooded workings in times of summer flash floods.

The principal mine entry will reduce underground transportation distances if centered in respect to the entire ore body. However, a "central" location may conflict with topography, lowest ore occurrence, and other features, and the optimum location will be one to best satisfy all conditions. Where an elongated ore body strikes roughly parallel to the direction of a proposed adit it is more practical to drive the adit to intersect the nearest ore. Under certain conditions, it may be more practical to sink a shaft through waste near the perimeter of an ore body rather than to locate it centrally.

Ore bodies on the plateau may deviate irregularly from the horizontal. An ore body may dip with the enclosing beds, may cut across the bedding or may occur as splitting and converging seams. An adit portal located at an elevation so that the adit intersects the lowest ore occurrence will eliminate inclines within the ore body and possibly eliminate an undesirable haulage system. The elevation of an adit portal should be such that on a predetermined grade the adit will intersect the deposit to allow easiest extraction of ore with the planned type of haulage. If the ore body dips radically or occurs at varying elevations, it may be best to locate the portal so that the terminal end of the adit is at the same elevation as the lowest ore, or under certain conditions it may be best to have the main haulage level below the ore and work through raises. This latter method will permit extracting the ore pillars without damaging the haulageways. Where ore occurs sporadically at varying elevations, haulageways at the elevation of or below the lowest ore have the advantage of facilitating underground exploration by long-hole drilling. A secondary haulage method such as slushing, small trackless diesel units, or hand tramming is then necessary to move the ore from the stopes to the chutes of the main haulage system. A shaft sunk near the deepest ore may avoid driving long haulageways in waste and sinking underground winzes and inclines. A shaft or adit entry penetrating an ore body at its lowest point will permit haulageway grades to favor loaded cars. If water is encountered, tapping the lowest point in the ore body will permit draining lateral workings to the shaft sump or through the adit.

The type and condition of overburden or surface rock should also be considered when locating a mine opening. The opening should be started in solid material if possible. It is not advisable to locate a mine opening where the entry must be advanced through loosely consolidated overburden. An adit portal started in unconsolidated material may require expensive spiling and costly maintenance. Sinking a shaft through unconsolidated material may result in the need of heavy cribbing and possible later realignment. Heavy rains may cause trouble when water drains through loose material around an adit portal or shaft collar.

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Existing workings should be used if they satisfy the requirements for the planned type of haulage system and if their use will result in a saving in development costs. The use of nearby existing workings may be the only condition that will permit mining a small deposit, although a haulage system adapted to existing workings may prove unfavorable. If such workings are horizontally or vertically erratic or too restricted in size, the resulting haulage costs may be excessive and it may be impossible to attain the planned rate of production. Also, the cost of rehabilitating and aligning existing workings for an adequate haulage system may cost more than the initial cost of a new entry.

The location of property boundaries and their relationship to the ore body and topographic features may affect the type or location of entry. Occurrence near a rim may favor access to an ore body by an adit, but conflicting ownership of the rim area may necessitate entry by shaft. The location of property boundaries also may limit waste dump room below a proposed opening and restrict the selection of its location.

The principal advantage of entry to an ore body by an adit when compared with entry by a shaft is the lower cost per foot of opening. The direct unit cost of adit advance may be from one-third to one-fifth that of vertical shaft sinking. Some of the reasons for the lower direct unit cost of adit development are: Greater daily advance because of easier and faster drilling, breaking, and rock removal; fewer men required; fewer specialized labor classes such as hoistmen and shaftmen; and generally less timber and supplies required.

The capital outlay for an adit surface plant is considerably less than that needed for a shaft, since hoisting equipment, headframe, and possible pumping equipment are not required. Consequently, for the same cost, an adit can be driven a greater distance than a shaft can be sunk.

An adit operation is usually less costly because of less maintenance and less handling of waste and ore. It has greater flexibility, and where water is encountered, little or no pumping is required. The disadvantages of adit entries increase with length. Ventilation may become a serious problem in mines developed by long adits, but it is also a problem in mines serviced by deep shafts.

Costs of driving average size adits on the plateau range from $20.00 to $35.00 per foot. In some cases, contract drifting in leasing operations is being done for $12.00 to $15.00 per foot, with the lessee supplying everything except pipe, track, and timber.

The term "incline" as used on the plateau is an entry for access to an ore body, driven on down-grades of from 10° to 25°. Some may be correctly classified as inclined shafts, although others are more nearly a slope-type entry. The term incline-adit has been used to describe these latter type entries.

Inclined shafts common to the plateau are those sunk on grades near 25° where the ore is hoisted in cars to surface bins by track haulage using small surface hoists (see fig. 10). The entry should be wide enough to permit passage of the ore car with room for the safe passing of personnel and for installation of ventilation, water, and compressed air piping. As a rule, ore cars can be used in inclined-shafts up to a maximum of 20° to 25°, but with steeper dips, skips are employed (see fig. 11).

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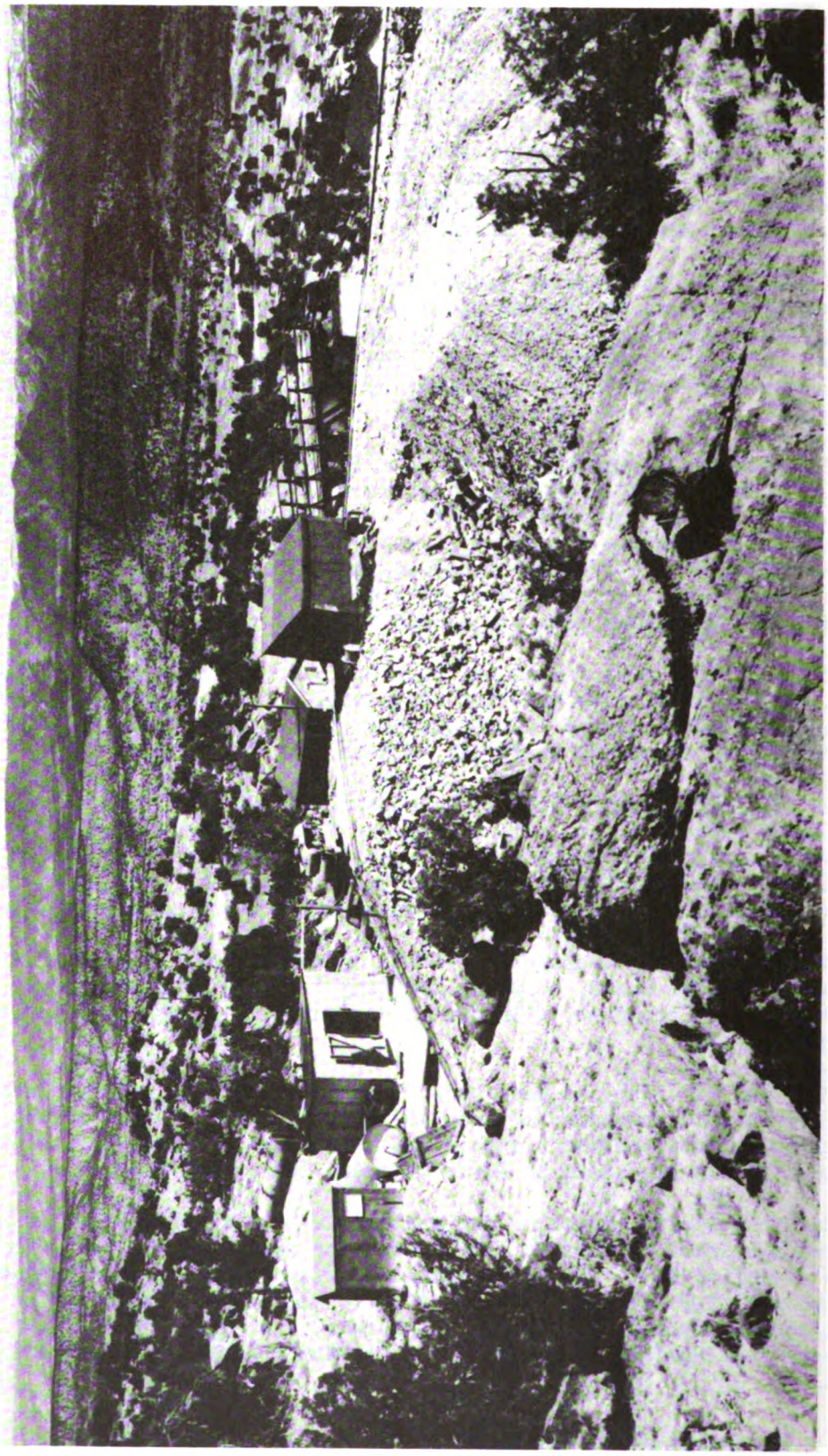

Figure 10. - Typical surface plant for inclined-shaft operation. Note: Trestle to steel ore bins.

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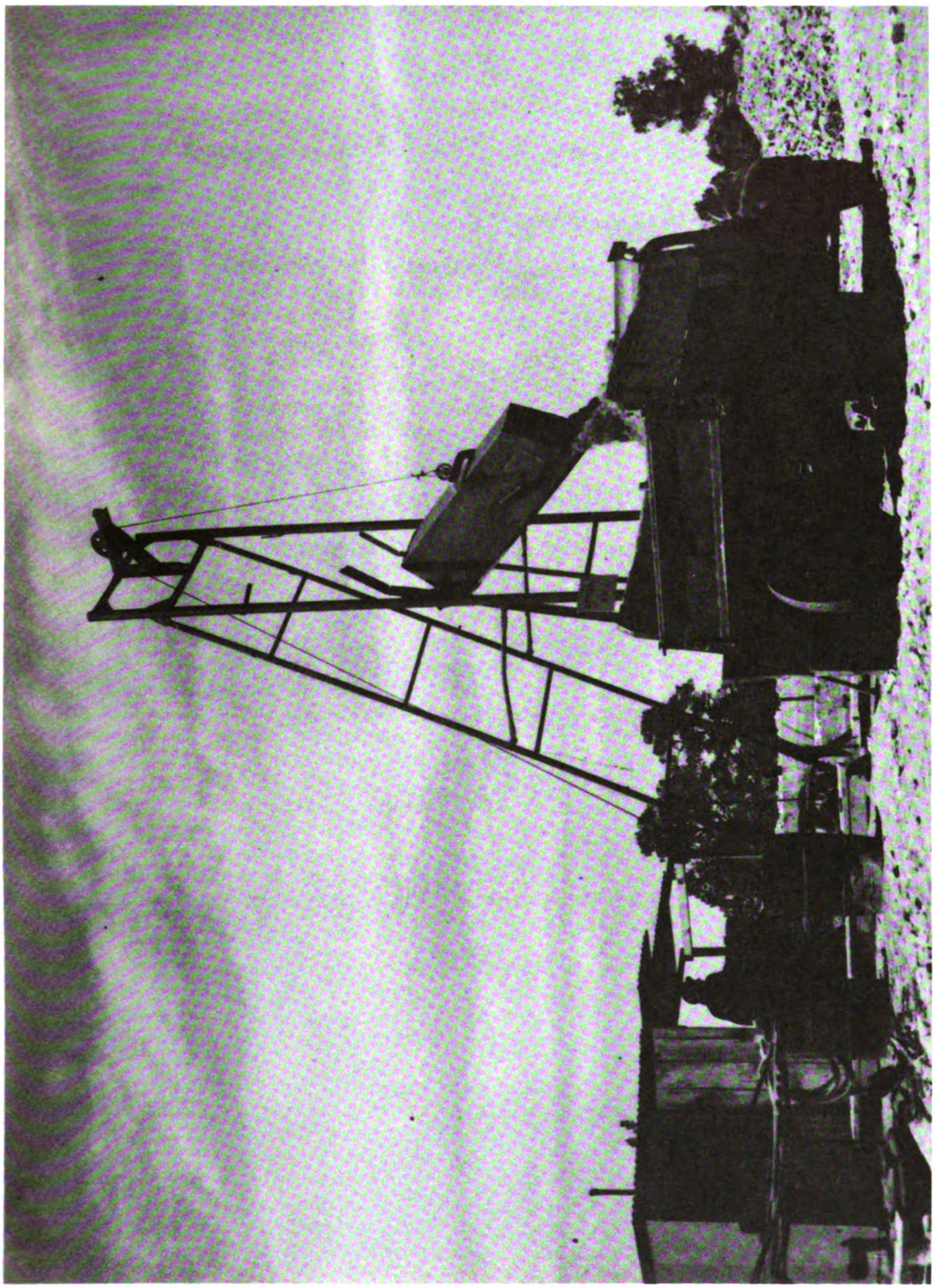

Figure 11. - Small welded pipe headframe and skip hoisting at small mine developed by an inclined shaft.

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The slope-type entry usually is larger and is driven on flatter grades and haulage is by large, self-propelled, diesel-powered units. The entries may be as large as 10 by 10 feet in cross-section with grades from 10° to 15°. The trackless-type haulage units may be dump trucks, tractor-loaders, tractor-pulled trailers, or other conveyances.

The thickness of an ore body, its size, and depth, are factors that affect the estimated rate of production and the life of a mining operation. They are important in determining if access should be by vertical shaft, inclined shaft, or slope-type entry. The large slope-type entries are restricted economically to thick deposits where the height of ore excavations will permit the use of large trackless-type haulage units. This type of haulage is not adaptable to thin deposits where costly overbreaking is necessary. Small haulage equipment is preferable in thin ore bodies. If such ore bodies are relatively near the surface, development by small cross-sectional size inclined-shafts, using track haulage on the levels, permits transportation of ore from or near the stopes to the surface without extra handling. In general, inclined shafts are favorable in developing relatively shallow, small-tonnage deposits, where the cheap direct cost of sinking and low cost of surface installations are advantageous. It is common practice on the plateau to employ vertical shaft development when the depth to the ore exceeds 150 to 200 feet.

Cost per foot for sinking an inclined shaft is slightly higher than that of an adit but less than that of a vertical shaft. An inclined shaft can be sunk much faster, less timber is needed, and the cost of surface equipment is less than that for a vertical shaft. When advancing an inclined shaft, rock may be removed cheaply using a scraper or tractor-loader.

The initial cost of installations necessary for hoisting from a vertical shaft will depend on the size and life of the mining operation and principally include costs of headframe and hoist house construction, hoist (see fig. 12), skip or cage, and loading and dumping arrangements (see figs. 13 and 14). The cost of hoisting facilities normal to the average size inclined-shaft operations on the plateau is much less because only a small hoist or tugger and possibly a skip with some type of dumping arrangements are necessary. An inclined shaft sunk from a slope or hillside permits ore bin construction at an elevation allowing easy and cheap dumping arrangements. Trestle construction may be necessary to permit dumping into ore bins where an inclined shaft is sunk from a flat-lying area. Construction of a trestle may be avoided by slushing waste material excavated from the shaft to make the required ramp between the collar of the shaft and the top of the ore bin or hoist station.

Wear on hoisting cable in an incline shaft is much greater than in a vertical shaft, and if idlers are used they must be maintained. Spillage from ore cars is a major cause of car derailments when hoisting in inclined shafts. The amount of ore and waste that can be hoisted from an inclined shaft by small ore cars is limited.

The direct cost of sinking a typical deep, vertical, two-compartment, timbered shaft averaged near $100.00 per foot. Indirect costs plus that for construction of the headframe, ore bins, hoist house, machine shop, and power lines averaged approximately $50.00 per foot. In another instance, the direct cost of sinking a shallow, vertical, two-compartment, cribbed shaft was about $75.00 per foot, and the cost for mine plant construction and installation was close to $40.00 per foot. Reported costs for sinking single-compartment, inclined shafts range from $25.00 to $50.00 per foot, depending on the size of opening and length of incline.

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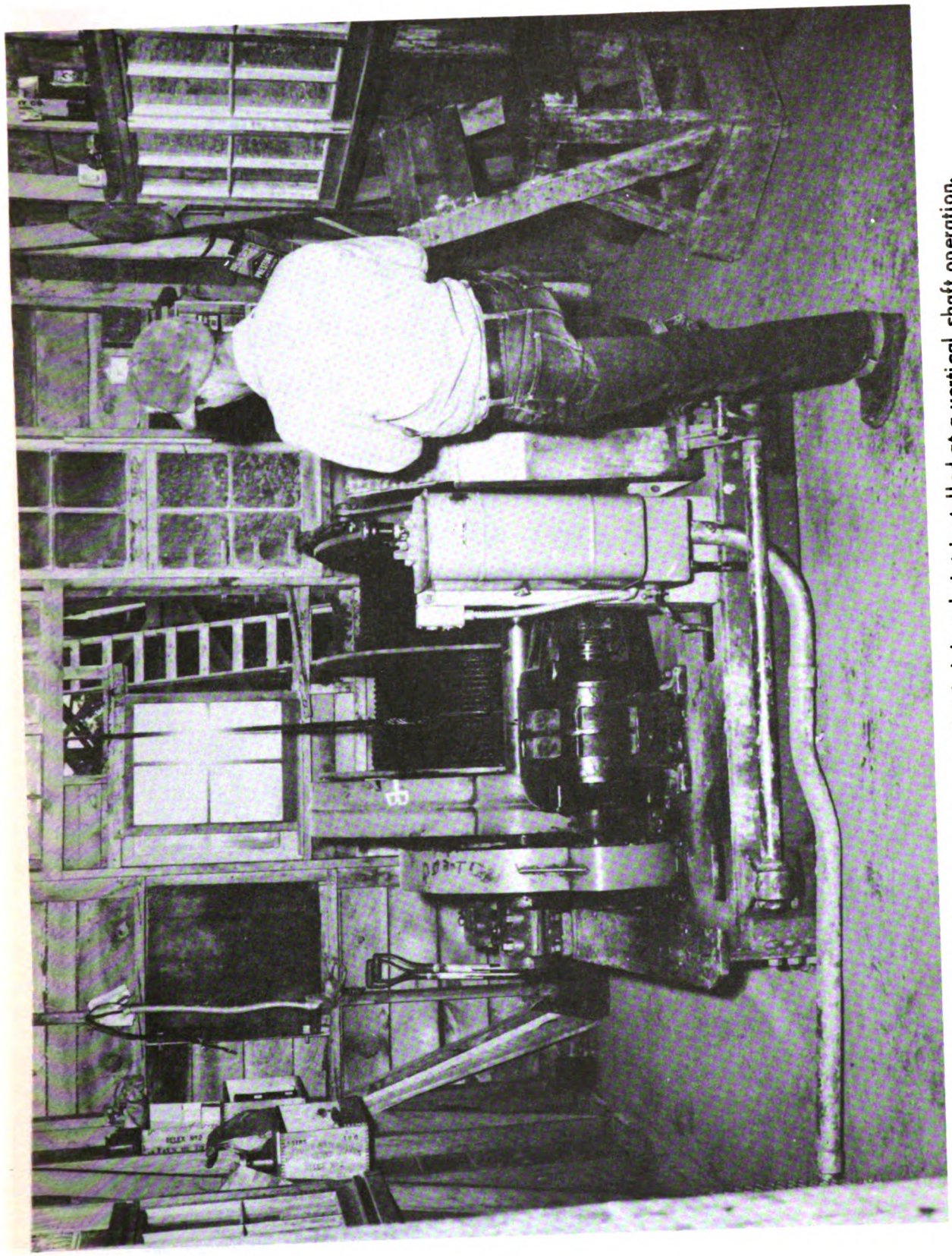

Figure 12. - A counter-balanced divided drum hoist installed at a vertical shaft operation.

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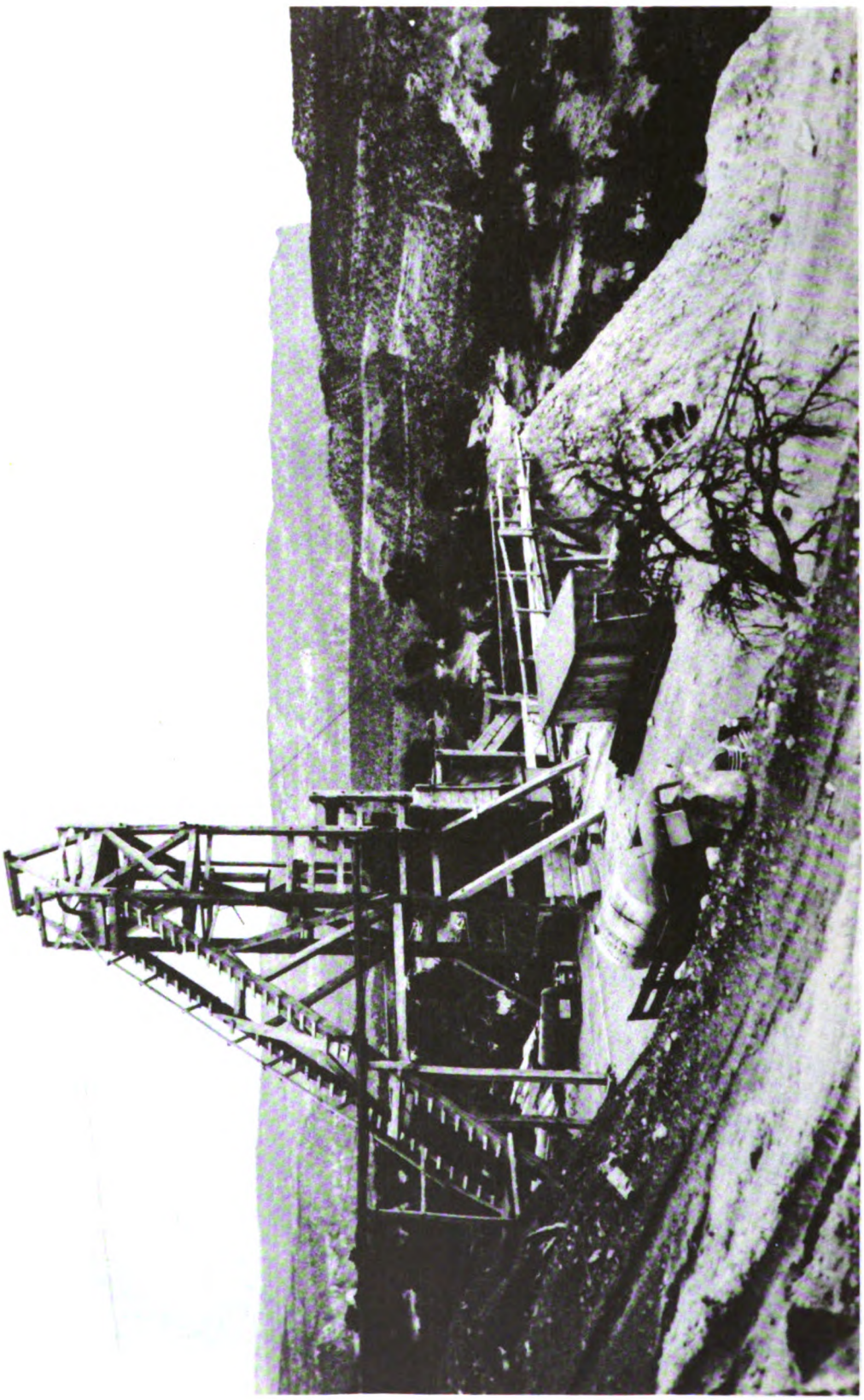

Figure 13. - Vertical shaft operation, wooden headframe.

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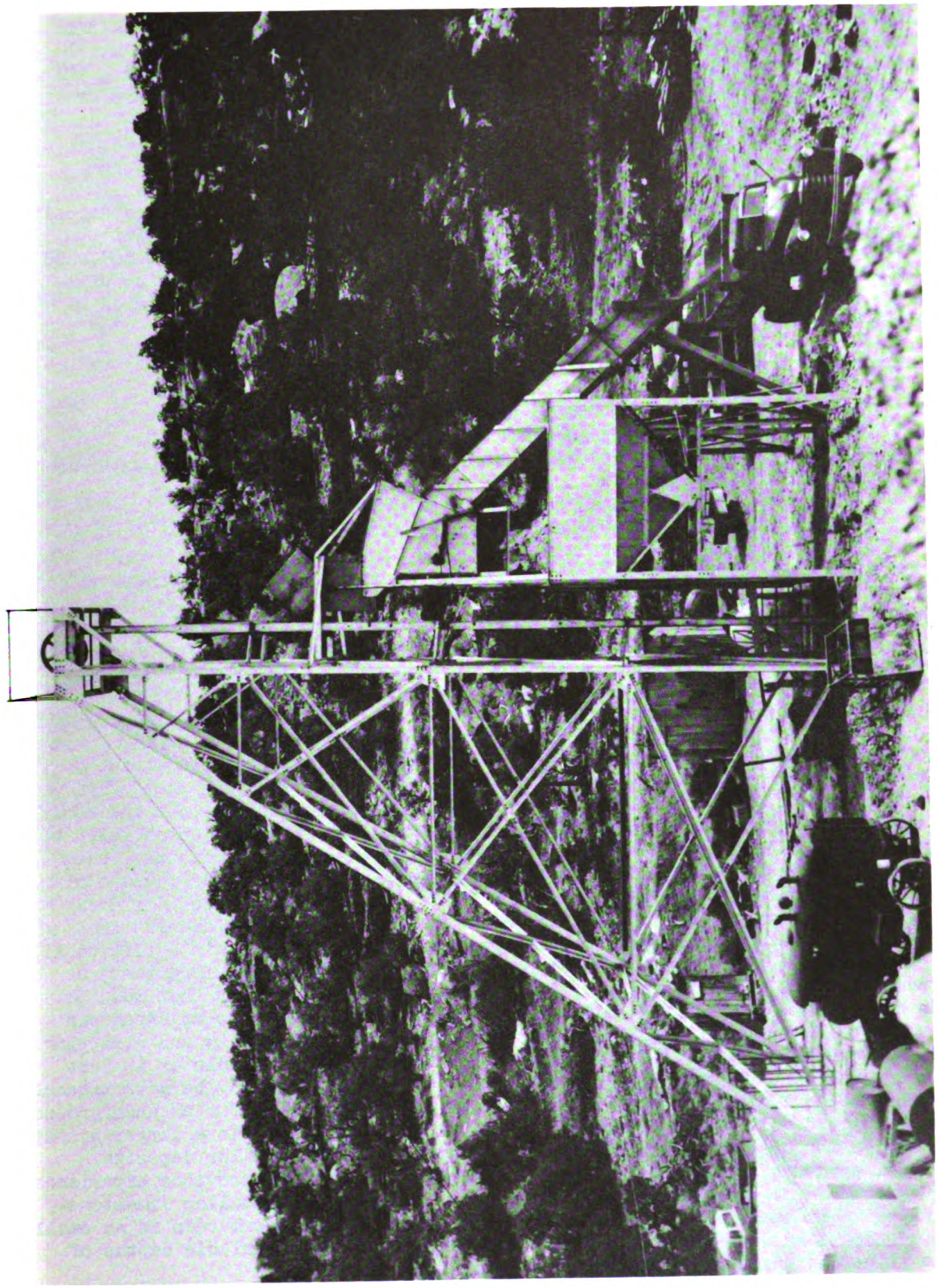

Figure 14. - Thirty-six-foot steel headframe, two 30-cu. ft. ore bins. Waste is trucked to waste dump.

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Access to small, isolated, and shallow ore deposits in the Temple Mountain District in Utah, is by vertical, 36-inch, calyx-drill holes. The depths to these ore bodies range from approximately 80 to 200 feet, and the cost of drilling these holes is reported to range from $30.00 to $40.00 per foot. Sinking buckets are used for hoisting (see fig. 15).

Open-Cut Development

The thickness of formations overlying the majority of the uranium ore deposits on the plateau immediately rule out open-cut mining. Because of the varied conditions involved no general criteria can be given as favoring this method, and the choice of whether or not to mine a specific deposit by open-cut mining will depend on the results of a study of the economics of that method as compared with underground methods.

Factors that will affect the choice of open-cut mining are:

1. Thickness and type of overburden.
2. Thickness, size, and grade of ore deposit.
3. Relative mining costs of open-cut method compared with cheapest underground method.
4. Extraction and dilution as compared with underground methods.
5. Available capital for purchase of equipment and for stripping.

The first two factors are closely related, for in any open-cut operation, the larger and higher grade the ore deposit, the more waste material that can be stripped. Stripping involves the removal of waste material directly over the deposit, as well as that surrounding the deposit, which must be removed to provide safe side slopes in the workings as the pit attains depth. Waste rock within the deposit must also be moved to permit mining the ore. One deposit in the Brushy Basin member of the Morrison formation is reported to require over 1 million yards of stripping. As the tonnage ratio of waste to ore increases the extraction cost per ton of ore increases because each ton of ore includes its pro rata share of preparatory and stripping costs. There is no general rule regarding the permissible amount of waste that can be removed for each ton of ore, but the ratio of waste to ore can be established for each deposit. This ratio is established to determine the extent of the deposit that can be mined by open-cut methods. When the established ratio is exceeded, it is necessary to resort to underground mining. Open-cut mining does not necessarily mean a lower unit extraction cost nor does this method necessarily allow the mining of lower grade ores. The deepest ore body on the plateau now being mined by an open-cut method is overlain by 110 to 120 feet of waste rock. The type of waste rock overlying a deposit is important, as the speed and cost of stripping will depend upon the amount of rock that must be broken by drilling and blasting before removal. Open-cut mining is advantageous when the total extraction cost per ton of ore, including preparatory and stripping costs, equipment costs, and interest and amortization charges, equals or is less than the total cost for an underground method. Open-cut mining may be advantageous even when the estimated unit extraction cost is higher than that for an underground method if a more complete extraction of ore will actually result in a larger profit. Cost studies for open-cut mining need not be complex for the smaller deposits. Many small open-cut operations of shallow deposits are based on previous experience and judgment of the operator. This is the case of some of the smaller limestone-type deposits in the Grants area of New Mexico. Most of the overburden is an easily stripped blow-sand and semiconsolidated sandstone, with small variable depths of barren limestone which requires breaking before removal.

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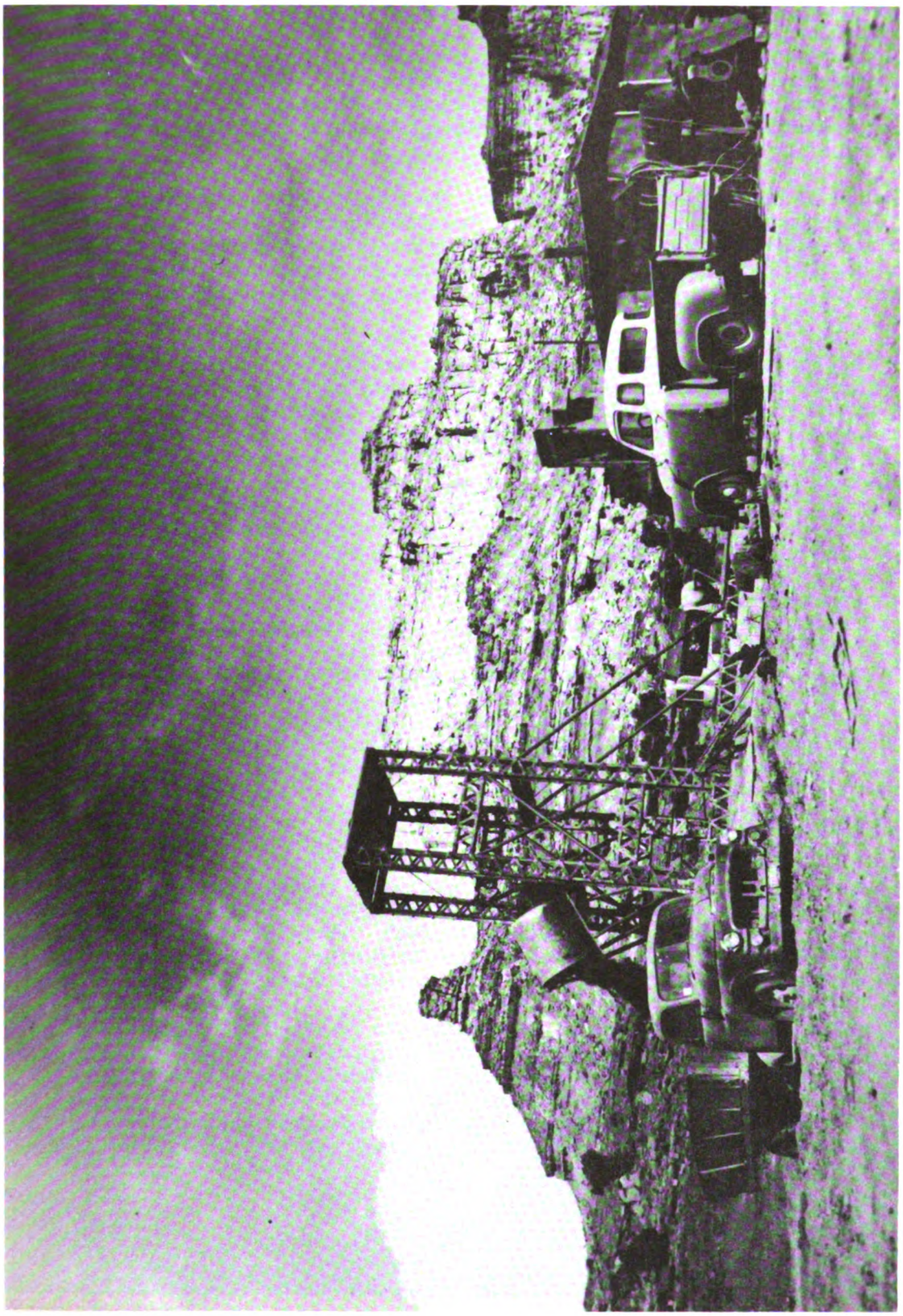

Figure 15. - Dumping ore from hoisting bucket using hinged dumping plate. Vertical circular shaft operation.

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Open-cut mining permits a more complete extraction of ore than most underground mining methods. This is especially true where the ore occurs as a persistent layer. Complete extraction of ore pillars is not always possible in underground methods, and the costs for pillar extraction may be high. An open-cut mining method was used at one of the larger mines on the plateau, not necessarily because of a cheaper mining cost, but principally because it allowed more complete ore extraction.

Dilution of ore with waste depends upon the care taken to maintain grade. Large equipment normally used in open-cut operations limits selectivity when mining small and irregular uranium deposits. Exposing large though irregular deposits by stripping may have an advantage in that it eliminates costly and possibly random underground development and provides a more complete picture of the deposit as a whole.

The usually larger initial capital outlay necessary for an open-cut operation, for the purchase of equipment, and for stripping, may be a disadvantage when compared to the capital expenditures required for an underground method. The amount of capital outlay will depend upon the planned size of the operation, which in turn depends largely upon the physical characteristics of the overburden and ore deposit. A small deposit under relatively shallow, easily removed overburden may require only a bulldozer and a tractor loader (see fig. 16) or a machine combining these features, a jackhammer, and a small compressor. For larger deposits it may be worthwhile to use power shovels and truck haulage, and where overburden is loosely consolidated to use tractor-scrapers. Using equipment on hand or that can be purchased cheaply is advantageous only when such equipment is suitable to the job to be done. Stripping by contract should be considered, because contractors have the necessary equipment and experience to do the job quickly and possibly at less cost. Where the estimated daily ore production and life of the mining operation are insufficient to permit amortization of equipment purchase costs, lower stripping costs probably will be obtained by contracting the work. Stripping by contract may not be cheaper if the amount of stripping is small or if the deposit is isolated and the contractor's cost of moving his equipment to and from the project must necessarily result in higher unit-excavation costs, if purchased equipment has a high resale value or a high rental value, or if amortization charges can be extended to other projects.

Reported tranching or stripping costs for small ore bodies using a bulldozer, range from $0.08 to $0.20 per yard for nonconsolidated overburden and from $0.50 to $2.00 per yard for rock that requires blasting. Typical costs for shallow rim stripping range from $0.10 to $0.50 per linear foot. Where a fairly large amount of stripping was to be done, the estimated cost of moving rock that required breaking was $0.80 per yard and that for unconsolidated material was about $0.30 per yard.

Although comparatively few uranium deposits can be mined by open-cut methods, serious attention should be given to this method if indications appear favorable. This method is receiving more attention now than formerly and undoubtedly could have been used to good advantage in mining some of the deposits now being mined underground. The ready availability of competent contractors with efficient earth-moving equipment and the advantages of more complete ore extraction and ease of mining favor use of this method.

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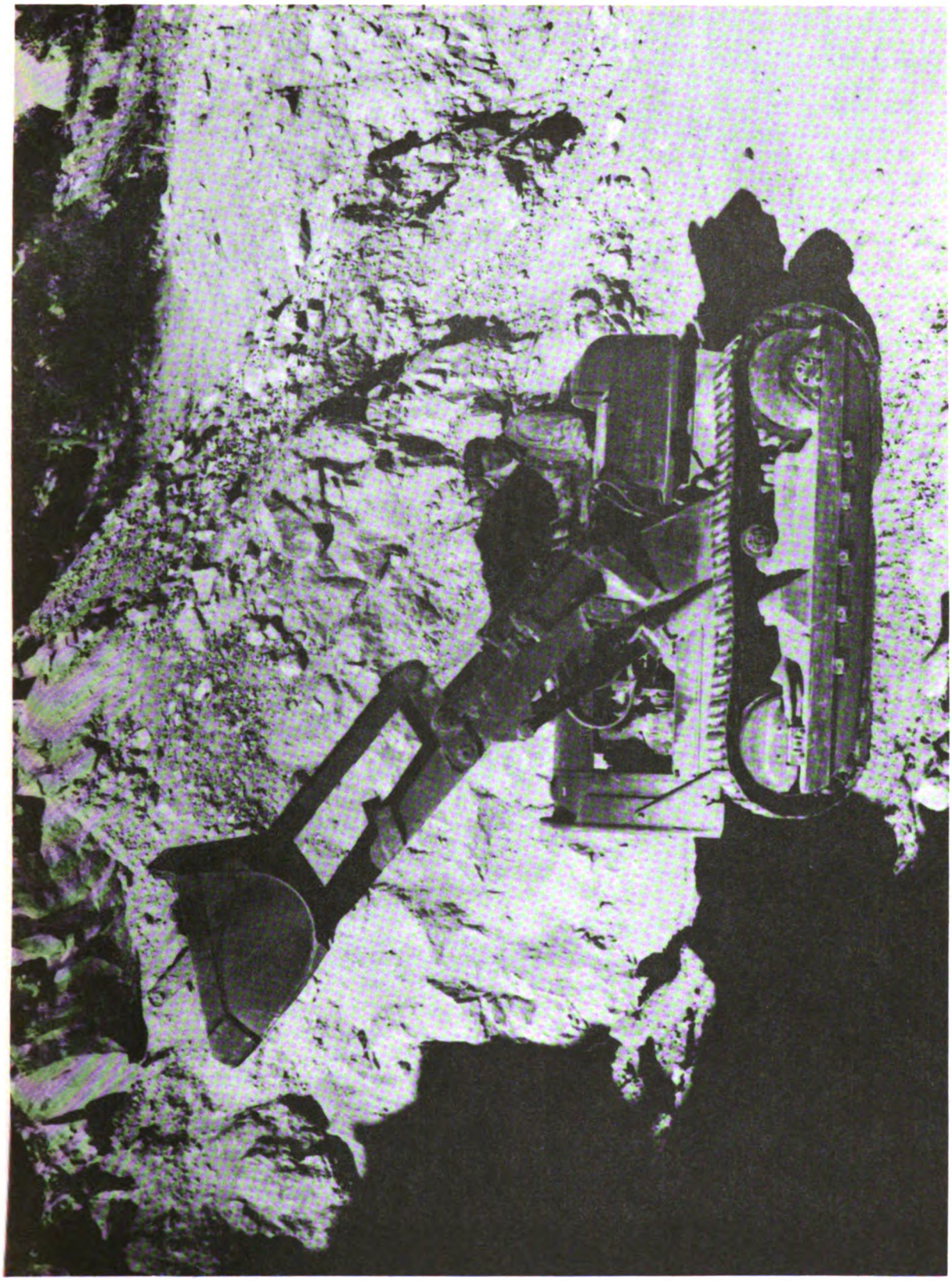

Figure 16. - Front-end type loader in open-cut mine.

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STOPING

Stoping is the excavation of ore underground. Open stoping methods are used on the plateau. Variations include open stopes without support, open stopes with pillar and timber support, and gophering.13/ Roof bolting is practiced in some mines as an auxiliary support method. Unsupported open stoping may be used in narrow elongated ore bodies, but with increased widths some back support may be necessary (see fig. 17). Pillar supported stopes may be by casual pillars of either waste or ore or by regularily spaced pillars as in a room and pillar method. Irregularly spaced pillars of waste provide support in large and irregular ore bodies. If the ore is persistent within a strata, a systematic room and pillar method of advance is often used, such as in the larger deposits in the Chinle formation. After reaching the limits of the ore body, ore pillars may be extracted by a variation of long-wall mining using cribbing, rock fill, timber, or roof bolting for temporary support while retreating. Small elongated ore bodies or a series of small interconnected lenticular ore bodies can be mined by gophering. The ore is followed along its irregular course and mined as found. Favorable indications of ore exposed in mining are explored by additional drifting. This method is used in many of the smaller deposits characteristic of the Salt Wash member of the Morrison formation.

Timber is rarely used except for supporting isolated local slabs. It may be used in a longwall retreating system where the ore is mined along a wall or face using timber stulls for protection near the face. In this system, roof support away from the face usually is of little concern and may even be advantageous to induce caving. Drywalling and back filling may be used for roof support; however, this method requires costly compaction of the fill to be effective. Back filling is sometimes used to dispose of waste, but later this may prove to be disadvantageous as low-grade material covered by back fill may be classified later as ore. In mines operating on A.E.C. leased ground, back filling is not allowed except with prior approval. This regulation is to permit reentry and possible remining.

The purchasing schedule for uranium ore indicates the advantage in shipping higher grade ores. Most mining companies establish and attempt to maintain a uniform cut-off grade for shipping. Ore-grade control is of major importance when mining erratic uranium deposits, although less attention to control is necessary in large deposits of fairly uniform grade. Ore and waste should be kept separated as much as possible to avoid dilution.

There are three methods of controlling ore grade before blasting. The first is by in-place sampling and chemical analysis. This method is the most accurate but is time consuming and costly, and therefore, it is little used on the plateau except for an occasional check. A common method of ore control is by measuring radioactivity. This is accomplished by scanning a rock face with a counter provided with a lead shield on the probe to minimize outside radiation. The third method is visual. The color difference of many uranium ores, in contrast to the host rocks, is usually an excellent guide to experienced miners when locating holes for blasting. The careful miner, by watching drill cuttings, need seldom blast waste material with ore. Although color of ore is a practical guide of ore grade, it is not an infallable indicator. Samples of the mineralized zone should be taken at frequent intervals for chemical assaying or checked by a counter as mining progresses. Failure to do this has resulted in the failure to recognize ore and, conversely, shipment of nonpaying ore to the mills.

13/ Jackson, C. F. and Gardner, E. D., Stoping Methods and Costs: Bureau of Mines Bull. 390, 1937, p. 4.

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Figure 17. - Pillar-supported open stopes. Pillars are ore and will be extracted when retreating.

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Separate blasting of ore and waste is often required to maintain ore grade when mining erratic ore bodies. Deep rounds are not advisable if ore is to be cleanly mined in this type of deposit. Mining costs are increased where separate blasting is practiced, but the increase is usually more than offset in the recovery of a higher grade product. Attention should be given to fines when cleaning up waste for often the fines are of ore grade. Fines can be separated by a simple screening process. Sub-grade material, that must be excavated as mining progresses, is often blended with higher grade ore.

Underground long-hole drilling is a practical method of exploring for knknown ore extensions, especially where close-spaced drilling from the surface is not economical by reason of depth. Cuttings from long-hole percussion drilling, correlated for representative distance, may be saved and checked chemically or radiometrically, or the holes may be probed. Diamond core drills are seldom used for underground exploration because of the higher unit drilling cost. Some ore bodies, particularly those in the Salt Wash sandstone, tend to divide into two or more mineralized horizons separated by barren rock. This condition often exists in the Salt Wash where the ore is relatively thick, and test holes should be drilled into the back and floor to insure that all of the ore is found.

Standardized drill rounds are impractical in stoping small ore bodies, and the spacing and pointing of the drill holes will depend on characteristics of ore occurrence. Standardized drill rounds are used to advantage in stoping large ore bodies where the area and grade of ore at the face and the grade of ore behind the face remain relatively constant (see fig. 18). Blasting procedure differs little from that practiced in other metal mines. Strength of explosives used ranges from 30 to 60 percent by weight, depending upon the preference of the operator. Because of the general character of the rocks, 30 percent explosives are generally adequate. Miners unaccustomed to this ground experience some difficulty in breaking rounds cleanly where the rock varies in toughness stratigraphically.

Generally, the host rocks are easy to drill. Rock drills favored on the plateau weigh 35 to 55 pounds and are supported by pneumatic legs (see fig. 19). Telescoping short legs are used to advantage in thin ore bodies (see fig. 20). The same size drills are often used on jumbo mountings. Size of drill steel ranges from 7/8-inch hexagonal to 1-1/8-inch round, with the smaller diameter steels in more general use. Drill bits may be detachable or integral with the steel and often have tungsten-carbide inserts. Even though the rocks drilled are generally soft, the air compressor should have sufficient capacity and pressure to operate the drills and other air-operated equipment efficiently. Air lines should be large enough to allow delivery of the air to the working face without undue line losses. Air leaks should be avoided as they are wasteful and can reduce the efficiency of the rock drills. Drilling must be done wet to decrease the hazards of dust and to comply with the State mining laws.

Underground exploration and development is an important phase in any mining operation. When proved ore reserves diminish, additional emphasis should be placed on exploration and development of new reserves to maintain a steady production. The Atomic Energy Commission, aware of this problem, has provided a development allowance of $0.50 per pound of U_3O_8 contained in acceptable ores. Amount and cost of development work must be certified when production exceeds 1,000 tons per year.

In summation, the proper stoping method is the cheapest method of mining that will permit the greatest degree of extraction. Initial planning is important for a smooth mining operation and consideration must be given to a systematic method of

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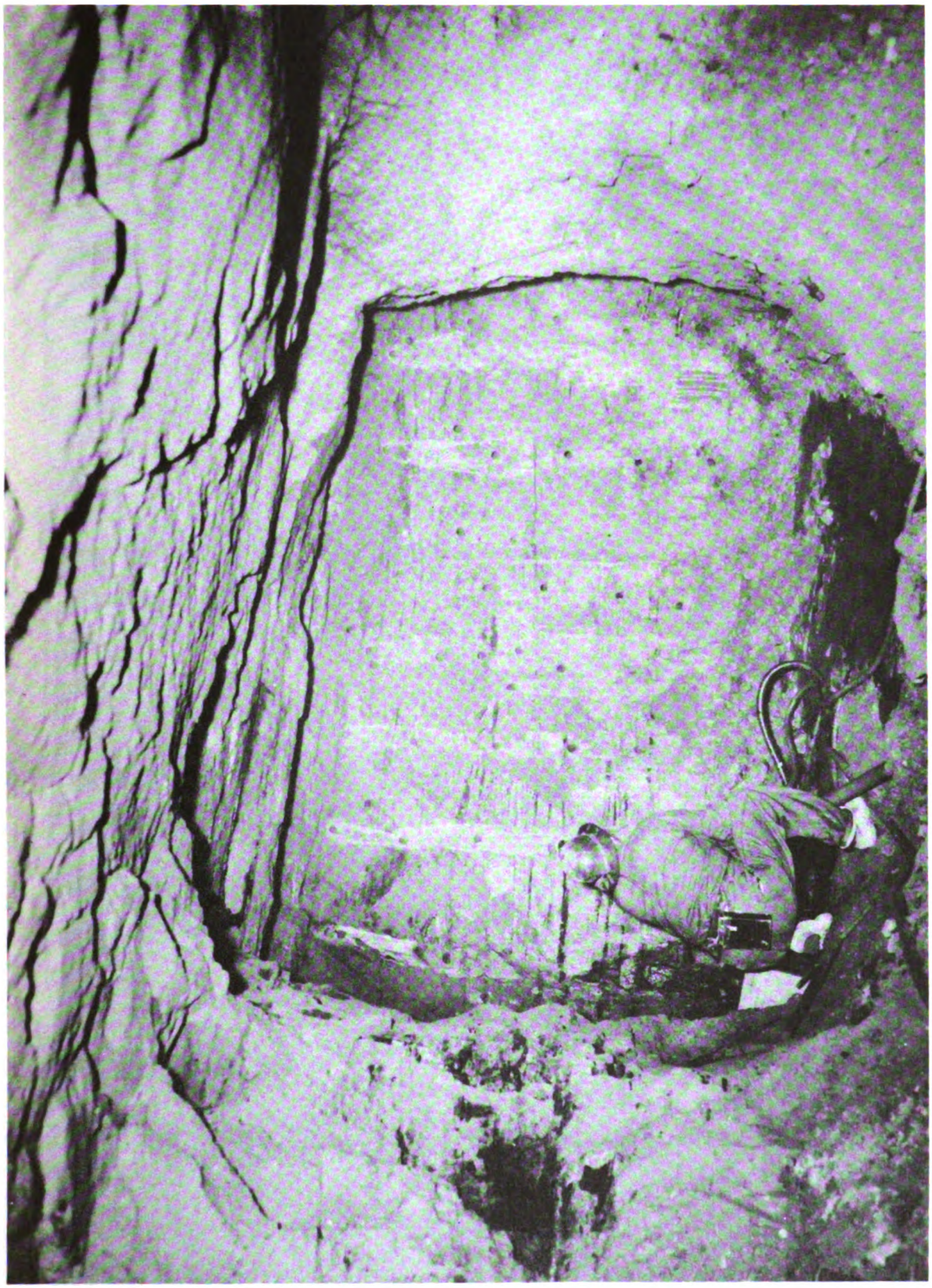

Figure 18. - Forty-five-hole drill pattern in ore that averages about 8-feet high.

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Figure 19. - Collaring a blast drill-hole using a jack-leg type percussion drill.

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Figure 20. - Drilling blast round in thin-bedded ore. Scraper in foreground.

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retreat if necessary for extraction of ore pillars. Selective mining, depending upon the characteristics of the ore body, must be practiced to maintain the grade of ore. Keeping exploration and development abreast of mining will ensure a fairly uniform rate of production.

UNDERGROUND TRANSPORTATION

Underground transportation is the handling and movement of ore from the stopes to the surface. It also includes the handling and transporting of waste, mining equipment, and supplies. Underground transportation costs are an appreciable percentage of the total mining costs, and when planning mine layout, underground transportation deserves careful consideration to secure high efficiency and low cost.

Haulage

Underground haulage is of three principal types: Hand tramming, animal haulage, and mechanical haulage. The underground haulage method selected should be one that will most easily and cheaply accomplish the job, and the choice depends upon the size of the deposit, its manner of occurrence, planned rate of production, and available capital. The grade and cross-sectional size of haulageways should be planned to meet the requirements of the equipment to be used. Use of equipment on hand will mean an initial saving to the project if conditions warrant its use. Particular caution is stressed not to over-mechanize, especially for small and irregular ore bodies.

Both track and trackless-types of underground haulage methods are used on the plateau. Trackless-types used are wheelbarrows, rubber-tired, horse-drawn cars, 3-wheel, diesel-powered dump cars, tractor loaders, and various types of dump trucks. Track-types of haulage include hand tramming of small ore cars, horse-drawn cars, and locomotives powered by compressed air, storage batteries, or diesel engines.

Hand-tramming generally favors the small operator with limited investment capital. It is economically adapted to mines where small output comes from scattered areas and where the operational life of the mine is short. Other factors that favor the choice of hand-tramming are short length of tram and irregularity of ore occurrence. Hand-tramming is sometimes used in combination with either animal or mechanical haulage where ore is transported from the working places to underground loading points. In thin, flat-lying, but undulating uranium deposits, grades may be such to eliminate hand-tramming and necessitate mechanical methods. Ore from small and irregular deposits near rim exposures may well be hauled cheaply by wheelbarrow. In one shallow, shaft-developed mine, two lessees transport ore and waste by wheelbarrows a distance of about 150 feet. Monthly production from this mine averages about 20 tons and comes from small and erratic pods. Here, wheelbarrow haulage is adequate. Wheelbarrows are used in some large mines as a secondary haulage method to move ore from stopes to loading chutes (see fig. 21). Diesel-powered wheelbarrows are a unique variation. Hand-tramming small ore cars also is best suited to mining comparatively small deposits where tramming distances are relatively short and are on suitable grade. The tonnage that can be transported is limited and transportation costs increase with length of tram. Light, end dump steel ore cars with capacities of from 16 to 20 cubic feet are the most popular for hand-tramming. Track gage usually is 18 inches and light rails weighing 12, 16, and 20 pounds per yard are used. When hand-tramming is planned, the grades of the haulageways should favor the loads so that loaded cars can be pushed with minimum

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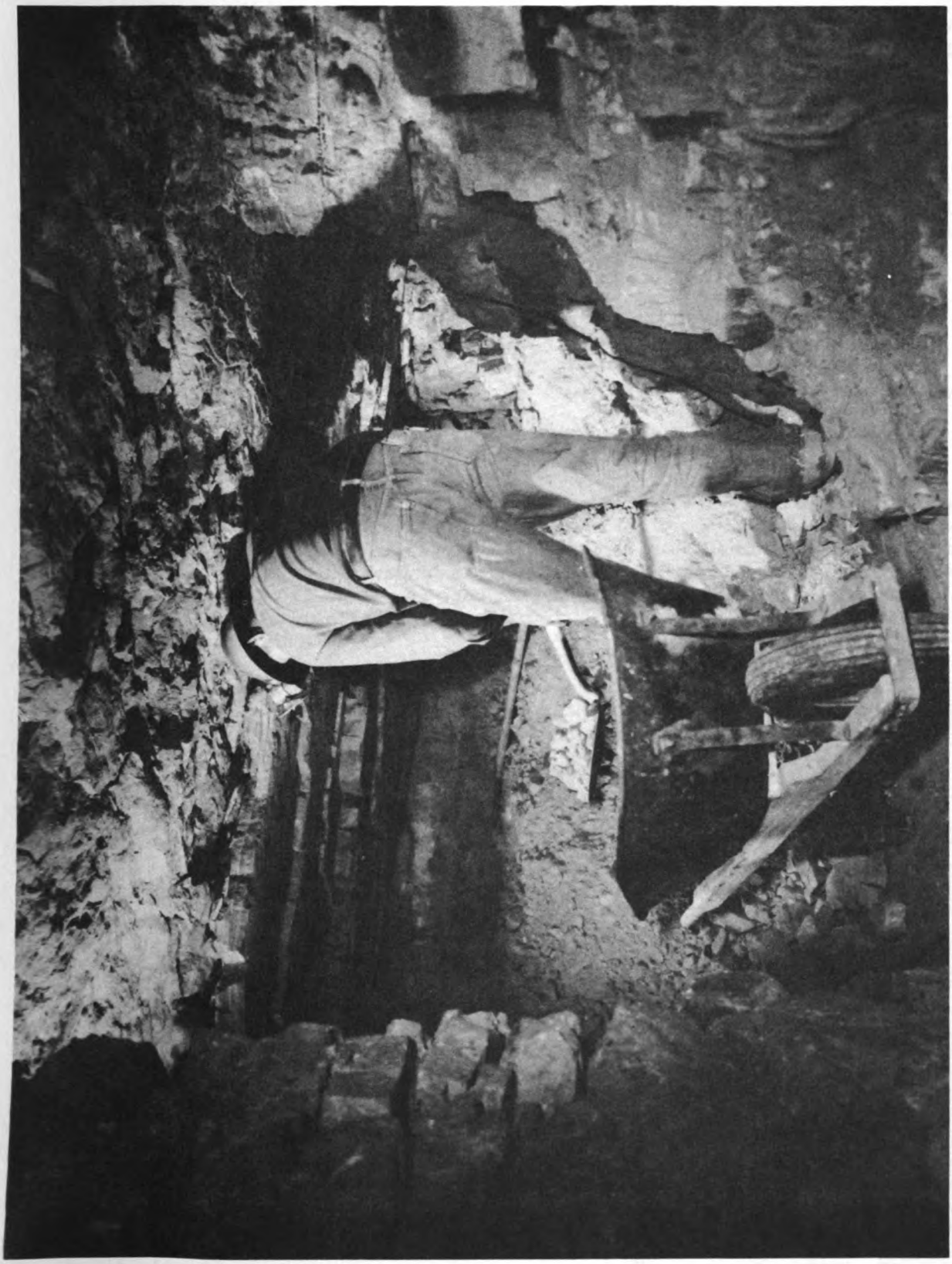

Figure 21. - Hand-loading ore into wheelbarrow in small mine.

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effort. Theoretically these grades are such that once started the cars will run with little or no assistance; however, the effort required to return the empty car to the working face must be recognized. Depending upon the condition of the mine cars and rail, track grades for hand-tramming should range from 0.67 to 1.4 percent.14/ Often little attention is given to track conditions where hand-tramming is employed, although for efficient hand-tramming, as well as for efficient motor haulage, close spaced, well-tamped ties to prevent sagging of the rails, proper gage clearances, especially at switches and curves, and clean track are necessary. Hand loading is usually practiced when hand-tramming, although chute or mechanical loading methods are also employed.

Animal haulage is used in some of the small operations developed by adits on the plateau, usually under conditions similar to those favoring hand-tramming. A logical application of this method is where unavoidable steep grades restrict hand-tramming but are not severe enough to necessitate rope haulage. Animal haulage has an advantage over hand-tramming in that greater tonnages per trip can be trammed longer distances. A horse-drawn, two-wheel, rubber-tired, 1-ton capacity car is used in one adit-developed operation where tramming distance is greater than 700 feet (see fig. 22).

Mechanical haulage may be track or trackless-types. Locomotives available for track haulage are of standard manufacture that have been proved in other mining areas and adapt well to uranium mining wherever grades are suitable. Locomotives cannot be used efficiently when following steep dipping or undulating deposits. Low-pressure compressed-air locomotives have found favor with many operators on the plateau mainly because of their low initial cost (see fig. 23). This type of locomotive can handle the production from the average size uranium mine. Battery-type locomotives have the advantage of transporting large loads at faster speeds over long distances but are limited to mines with an electric power source for battery recharging. Initial cost, rate of batter depreciation, and the installation cost of charging stations economically restrict their use to mines of sufficient daily production and operational life to permit amortizing these costs.

Trolley-locomotives are not adaptable to a majority of the mines on the plateau because of their high initial cost and the high cost of heavier track, track bonding, and trolley wire installation, maintenance, and guarding. The required electric power is not available in most of the plateau area. Larger haulageways with long curve radii are necessary, because of the size of these locomotives, and add to the cost. Generally, trolley-type locomotives are not suitable when mining irregular deposits.

The machine best suited for loading conventional mine cars in drift headings is the track-mounted, compressed-air operated, overhead mechanical loader (see fig. 24) The height required for operating the most popular size of this type loader is about 7 feet. Where the ore body occurs above the track level, mine cars can be easily loaded directly from ore chutes. If the chutes have sufficient capacity, they act as storage bins and may eliminate some lost time of the tramming crew. Often, when mining above the track level either near the end of a haulage drift or where access beyond that point in the drift is not necessary, the ore can be scraped directly into the drift where it can be loaded into mine cars by a track-mounted mechanical loader. Mine cars can be loaded from a breast of ore at track level too low to permit use of a mechanical loader or from a breast dipping steeply down from the track level by scraper and movable scraper slide.

14/ Jackson, C. F., Some Notes on Underground Transportation: Bureau of Mines, Inf. Circ. 6326, 1931, 40 pp.

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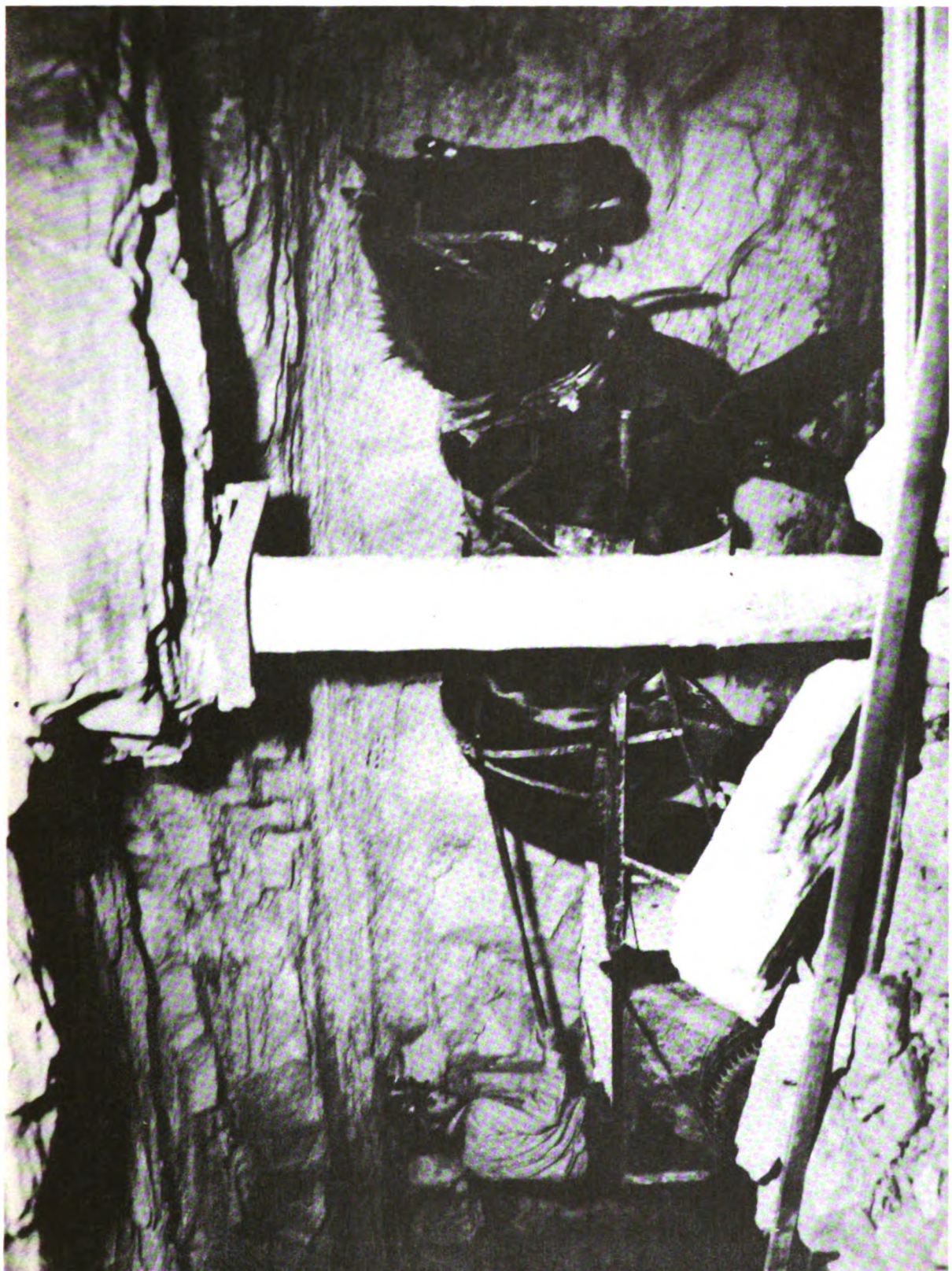

Figure 22. - A horse-drawn, 20-cubic foot, rubber tired, end-dump car used in small mine developed by an adit.

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Figure 23. - Compressed-air locomotive pulling mine cars of 16 cubic feet capacity.

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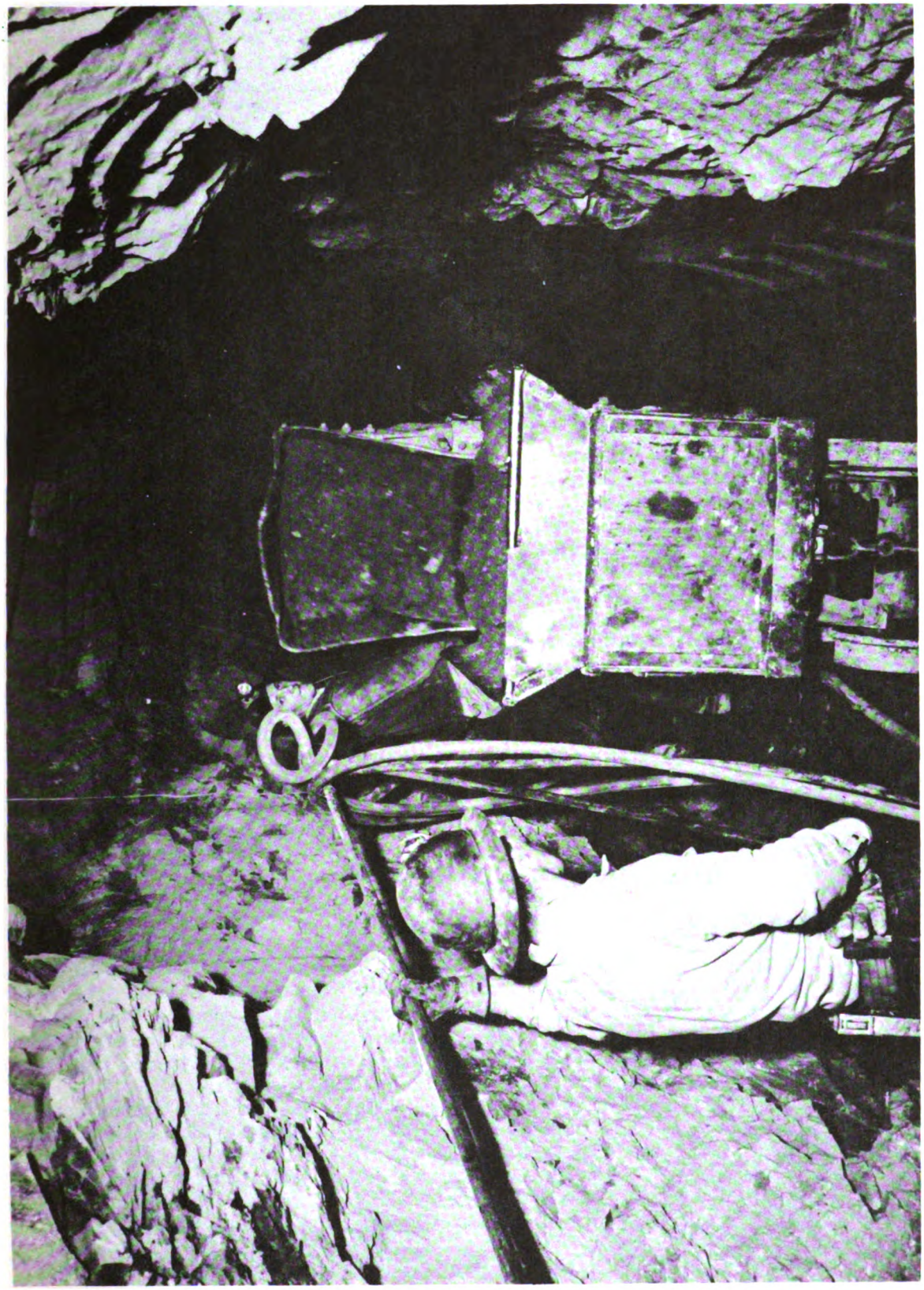

Figure 24. - Loading mine car of 16 cubic feet capacity with compressed air, over-head, mechanical loader. Note welded side extension on car to increase capacity.

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The small, self-propelled, three-wheel, diesel-powered, dump car is used extensively on the plateau as the main haulage method in small operations or for secondary haulage in larger operations. This vehicle has distinct advantages over hand-tramming because of its adaptability to longer trams and wide variations in grade. The capacity of these vehicles ranges from 16 to 20 cubic feet. The tonnage capable of being transported per day, as by hand-tramming, is directly influenced by the length of tramming distance. Length of efficient tramming for small operations, owing to their slow speed of travel, is usually 600 to 700 feet, although there are cases of longer trams. This car has advantages over rail haulage in that it can negotiate grades ranging from 10 to 15 degrees, and its maneuverability is an advantage in mining erratic curving deposits where track-laying costs may be high. However, it is subject to mechanical engine failures and requires smooth and clean haulageways. One mine operator has designed and fabricated 3-wheel, 20-cubic foot capacity, hand-dump cars powered by two 7-1/2-horsepower diesel engines capable of operating on 22 percent grades when loaded. A similar vehicle, which is particularly adaptable to thin ore bodies, operates on 100 p.s.i. compressed air and is capable of transporting about 600 pounds approximately 350 feet without recharging. The height of this vehicle is about 35 inches (see fig. 25).

Large trackless diesel haulage units are used on the plateau in mines developed by adits or slope-type entries. They are also used to move ore from large open stopes to underground loading points (see figs. 26 and 27). Dump trucks of various designs capable of handling large tonnages are used on grades as steep as 15 degrees. The larger haulageways required for such equipment restrict their use to thick deposits. Important advantages are their adaptability to undulating haulageways and their maneuverability. Their use also eliminates track installation and maintenance. Work stoppage owing to derailments and compressor or power failures, are reduced. Allied with use of diesel-powered equipment is the need and cost of adequate ventilation. Diesel exhaust gas conditioners must be properly maintained to absorb and dilute toxic gases and irritants.

A mine planned for large daily production, using large trackless-type haulage equipment, should also be equipped with loading machinery of sufficient capacity to maintain the operational cycle. Tractor-loaders, either of front-end or overhead dump design, are frequently used to load this type of equipment because of their dumping height (see fig. 28). Loading from large size chutes filled by large-capacity scrapers is a method that can be used where the haulage level is below the ore.

Underground scrapers serve a dual purpose as loading and conveying equipment, although as conveying equipment their operational distance may be short. Compressed air or electrically powered scrapers, operating in conjunction with scraper-loader slides, are used to load cars or trackless haulage units near the face of drifts or stopes and to convey ore or waste from stopes or drifts to loading chutes (see fig. 29). They are also used as a conveying method in sinking inclines. It is important that the horsepower and rope-speed of the scraper hoist, and the size, type, and weight of the scraper are suited to the job to be done. Scraper-hoist sizes most favored on the plateau are compressed air operated, rated at 5 to 7-1/2 horsepower; scrapers are usually 36 inches wide. Scraper loaders are movable slides or ramps upon which the scraper power units are mounted so that the scraper will deliver the material into the car (see fig. 30). An advantage of scrapers is their great flexibility. They can be used to convey material over negative or positive grades and can move material around corners. They are particularly advantageous when mining thin ore bodies.

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Figure 25. • Compressed-air-operated, trackless-type, dump car.

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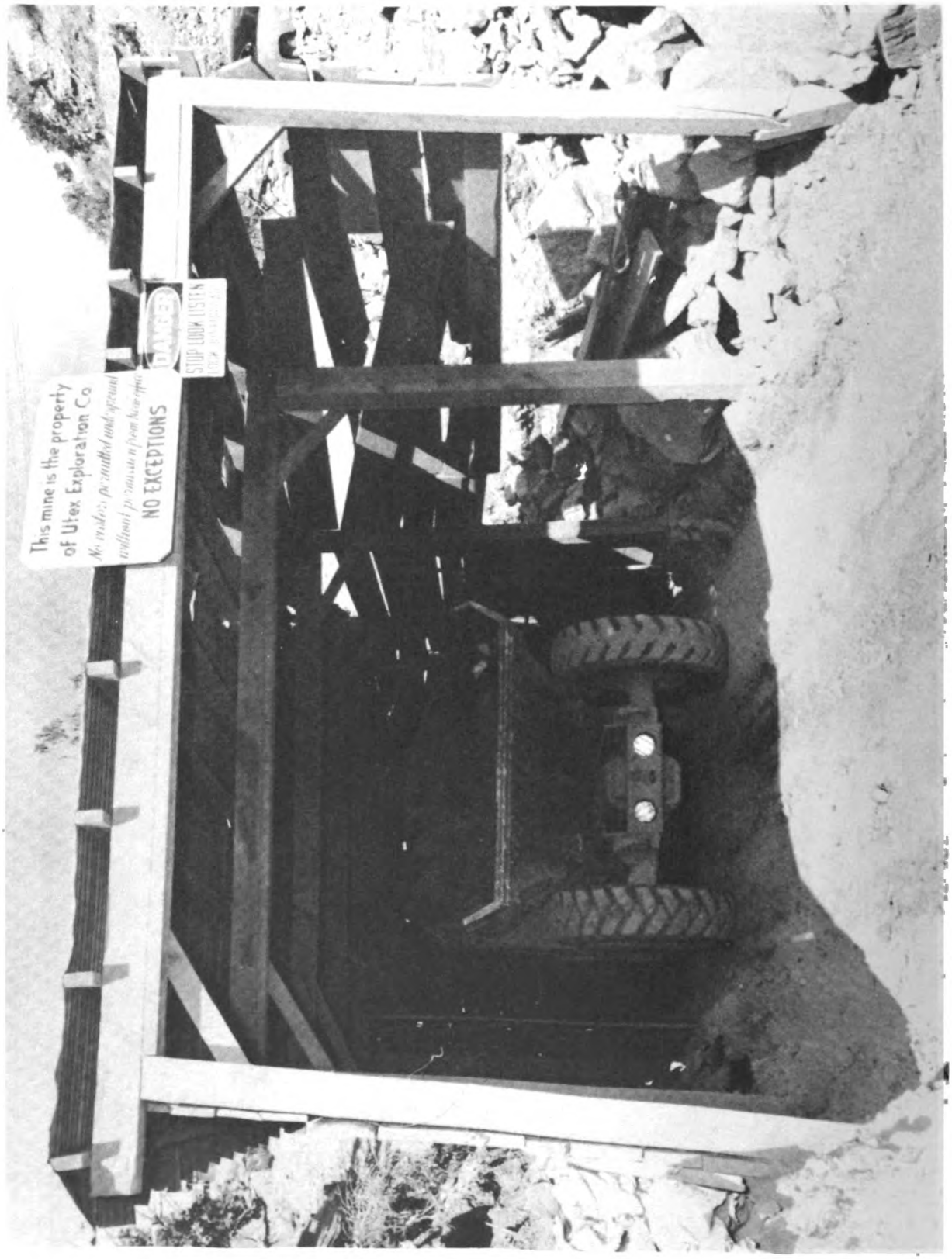

Figure 26. - Loaded front-end dump truck coming up slope-type entry.

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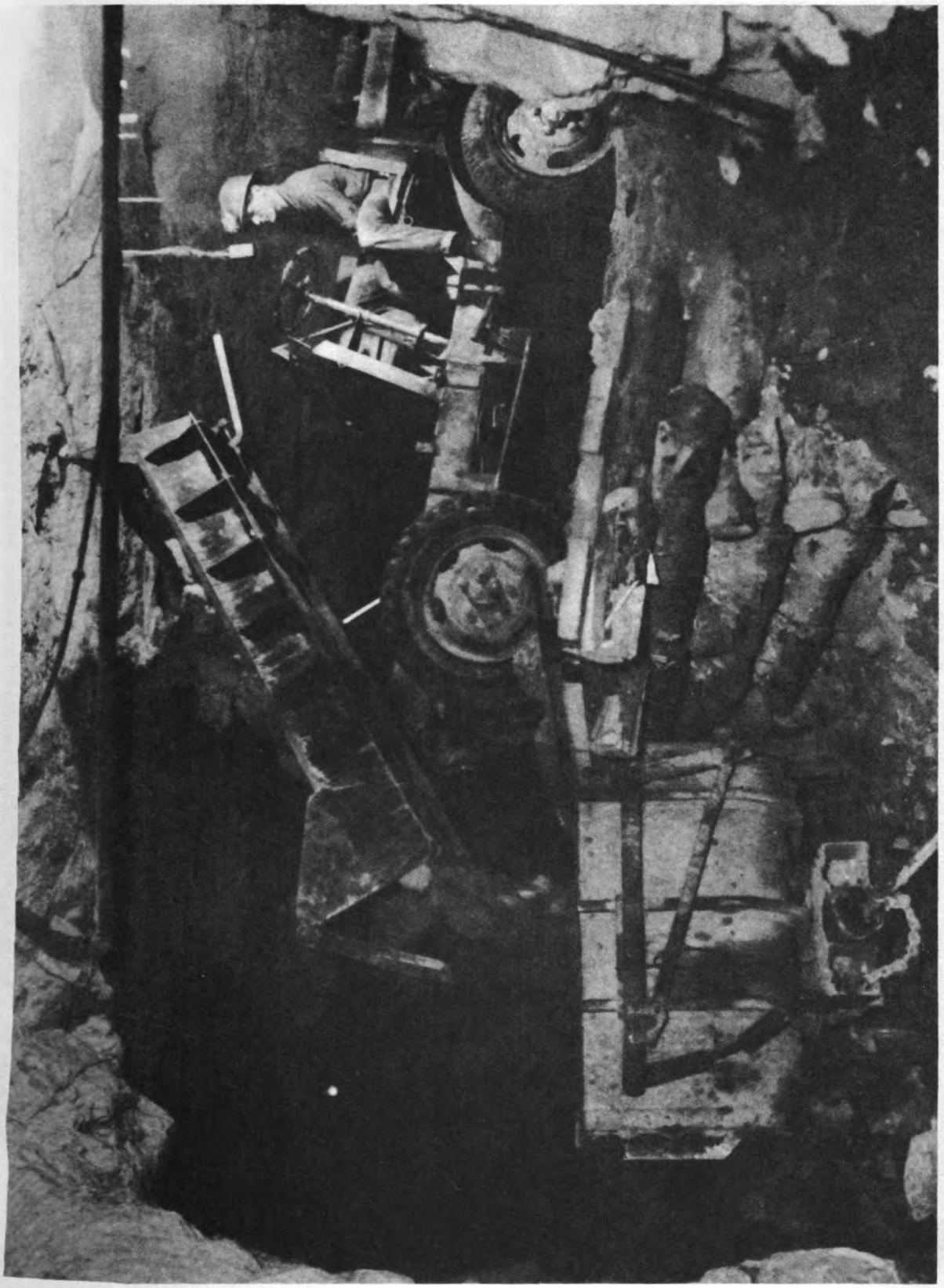

Figure 27. - Dumping ore from 4-wheel-drive, diesel, front-end dump truck into 56-cubic foot, Granby type car.

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Figure 28. • Front-end-type tractor loader in large, open stope used to load diesel dump trucks.

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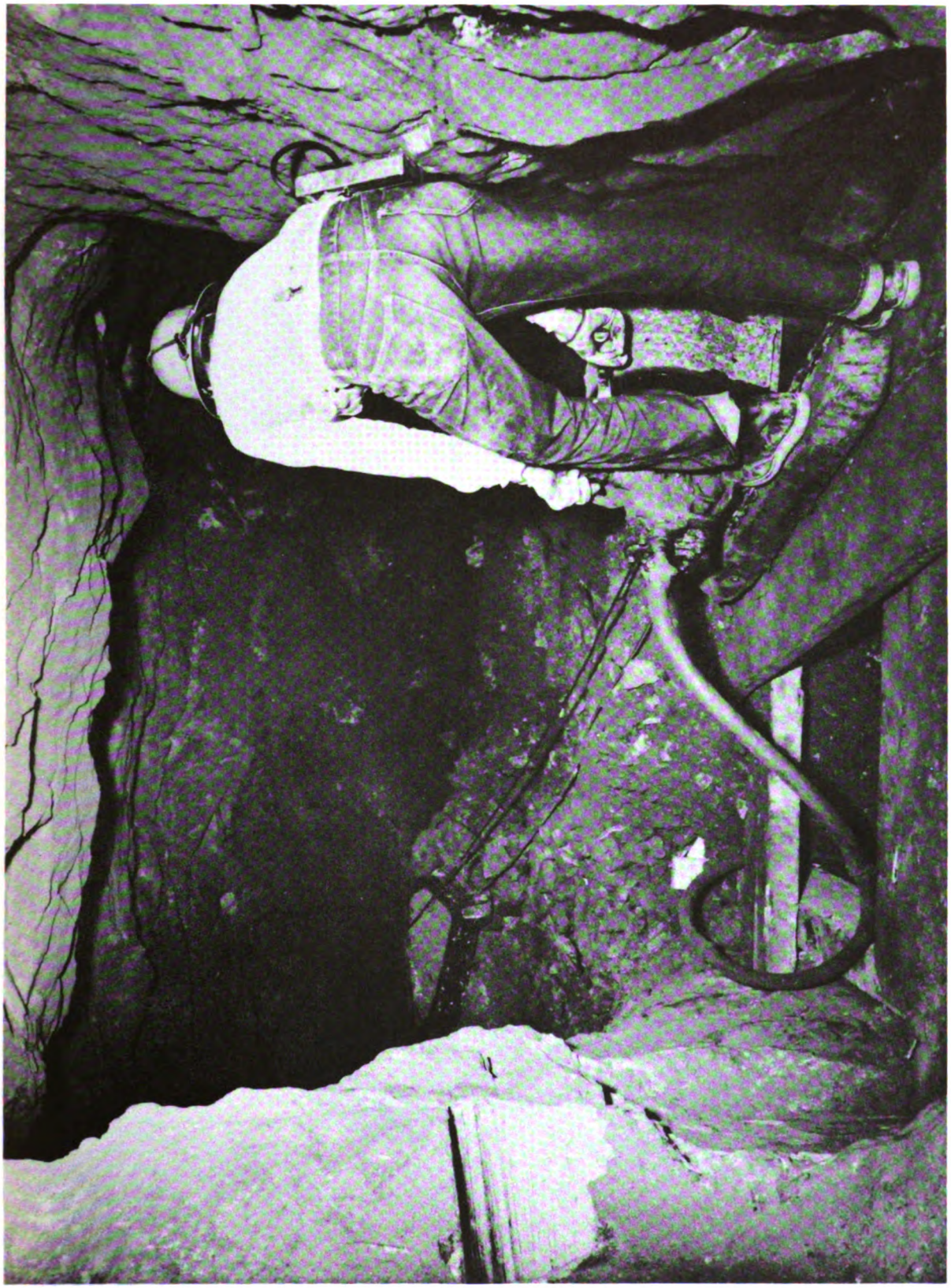

Figure 29. - Scraping ore from face to chute in open stope.

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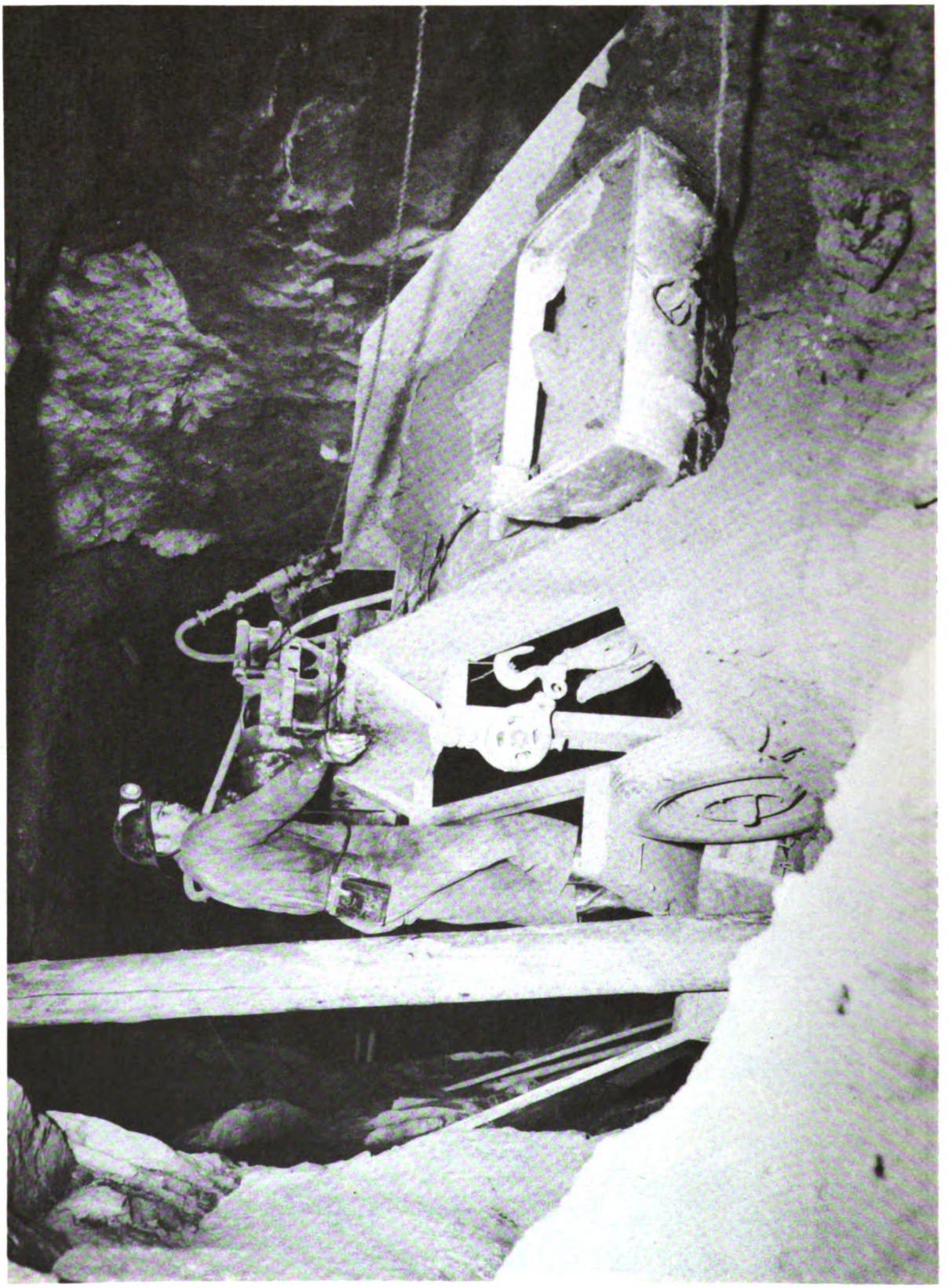

Figure 30. - Scraping ore up movable scraper loading slide into mine car of 16 cubic feet capacity.

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Hoisting

Equipment for hoisting must conform with the size and shape of the hoisting compartment and with the operation and services to be rendered. Hoisting from a vertical shaft may be by bucket, cage, or skip. Buckets are used in shaft sinking and for production hoisting in small shallow mines. This method of hoisting requires a minimum investment for hoisting equipment. Small steel or wooden head frames of simple design and provided with simple automatic dumping equipment can be used. The low initial cost may be important when the planned life of a mine is short or when it may be necessary to conserve capital during the early life of a larger mine. Size of buckets vary with respect to requirements and range from 5 to 20 cubic feet capacity. Bucket hoisting may be used to advantage in mining small ore deposits developed by small circular shafts as in the Temple Mountain District in Utah. The use of cross heads and guides in bucket hoisting are a safety measure required by some State mine safety laws.

Small, single-deck cage and car hoisting, and small single-skip hoisting are used in mines developed by vertical shafts. Each method has certain advantages and disadvantages. Under ordinary conditions, skip hoisting is more economical where large daily production is planned, although the daily hoisting capacity of each method is capable of handling the production from most plateau underground mines. The larger tonnage of waste or ore that can be hoisted per cycle favors use of a skip. Capacities of skips commonly used on the plateau are 30 to 48 cubic feet, whereas the size of mine cars used in cage hoisting are 16 to 20 cubic feet (see fig. 31). Initial cost for skip hoisting may be higher because of the cost of dumping facilities. Some mines on the plateau use skip pockets, but in others of similar daily production, small end-dump cars are dumped by hand directly into the skips (see fig. 32). Skip pockets have the advantage of permitting the use of larger capacity mine cars, such as the mechanically dumped Granby type. They also function as a storage bin permitting a smooth operational cycle.

In inclined shafts on the plateau, ore is generally hoisted in mine cars of 16 to 20 cubic feet capacity, though in several mines, Granby type cars of 56 cubic feet capacity are used (see fig. 33). Skip hoisting is not common. Skips can be used on steeper grades with faster hoisting speeds because of their lower center of gravity. The size of a skip depends on the planned rate of production, and, where used, methods of efficient loading and dumping are necessary. Where small mine cars are hoisted, a top man is necessary for dumping, but in small operations this work can be done by the hoistman. The need of properly laid track in inclined shafts is stressed. Rails of sufficient weight with uniform grade and correct gage and laid on well-tamped, close-spaced ties will permit faster hoisting speeds and will lessen the hazards of derailments.

VENTILATION

Mine ventilation is the distribution of air through underground workings to provide comfortable, safe, and healthful atmospheric conditions at working places. Ventilation may be natural, mechanical, or a combination of both. Natural ventilation is the movement of air in a mine produced by differences in the elevation of the mine openings or by a difference between the underground and outside temperatures. Mechanical ventilation is the forced circulation of air by fans and should be used where natural air movement is not sufficient. The fans may operate blowing or exhausting.

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Figure 31. • Topman caging mine car of 16 cubic feet capacity at surface.

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Figure 32 - Dumping hand-trammed, mine car of 15 cubic feet capacity into skip of 30 cubic feet capacity.

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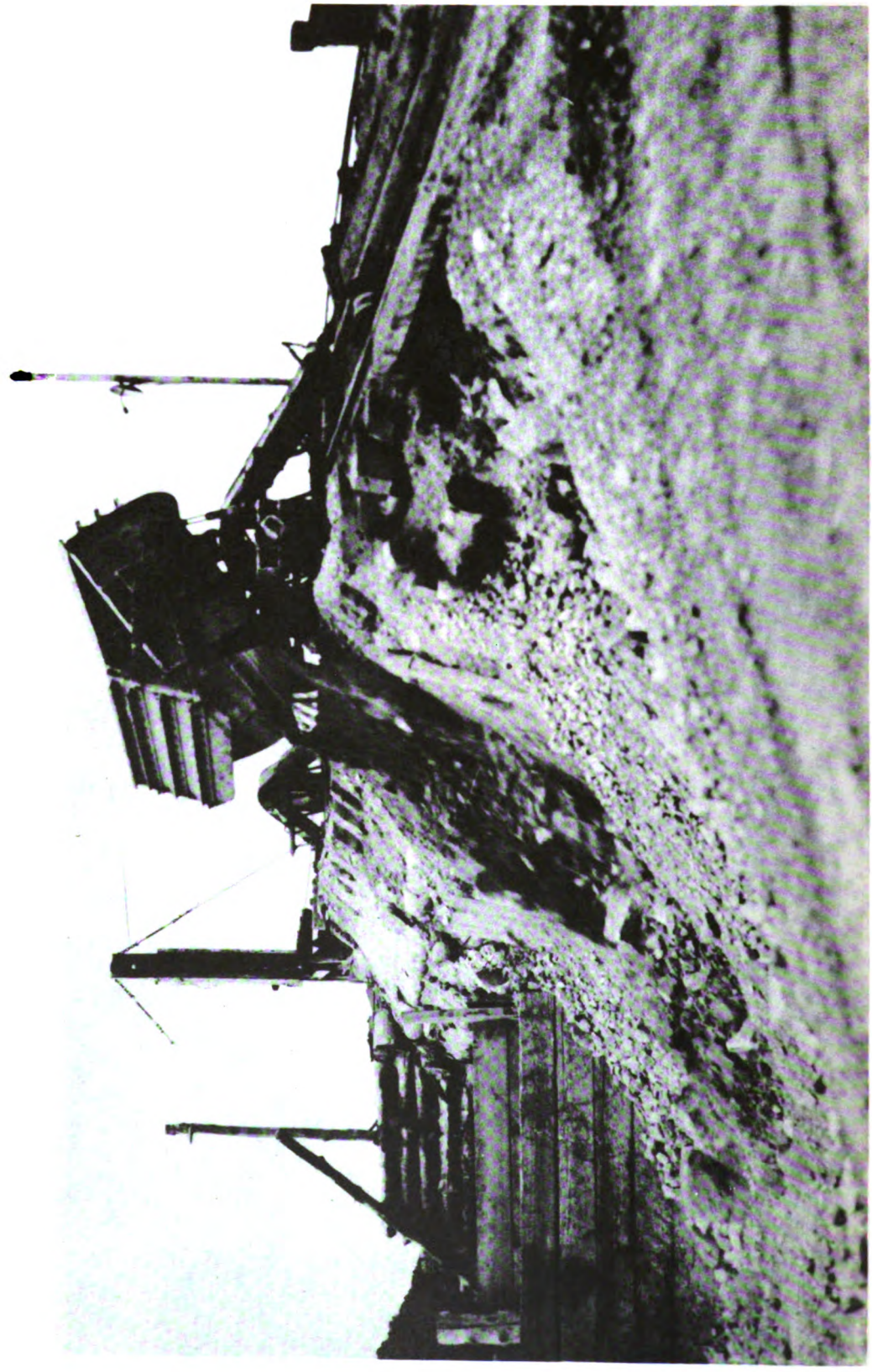

Figure 33. - Mechanical dumping of Granby-type, mine car of 56 cubic feet capacity at surface of inclined shaft.

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Air impurities in uranium mines include radioactive dust and gases, gas and smoke from blasting, dust from mining operations, and exhaust gases when diesel-powered equipment is used. These impurities may be irritating, toxic, or both. Breathing of men and animals, open lights, oxidation of timber, and diesel engines consume oxygen and produce carbon dioxide. Principal harmful gases composing the exhaust from diesel-powered equipment are carbon dioxide, oxides of nitrogen, oxides of sulfur, and carbon monoxide; irritants are aldehydes and smoke.

The Division of Occupational Health, U. S. Public Health Service, in cooperation with the Atomic Energy Commission, various State departments of health and mines, and other Governmental and private agencies, began a long-range study in 1949 to determine the health hazards in the uranium-producing industry. One of the probable health hazards in uranium mining is the damage caused to the body cells by alpha particles emitted from the radioactive gas radon and two of its principal radioactive decay products. Radon gas and dust contaminated by its daughter elements inhaled and carried into the lungs emit alpha particles in their process of decay with a potential hazard to lung tissue. Radon gas is dispersed into mine atmosphere by diffusion from uranium-bearing rocks and is released in drilling and blasting. Solid decay products of radon gas become attached to dust particles and water droplets present in a mine atmosphere. The permissible limit of radon or its equivalent daughter-element concentrations, as suggested by the U. S. Public Health Service, is 100 micro-microcuries per liter.15/

Proper ventilation and dust control will reduce hazards resulting from inhalation of radon and its daughter elements, reduce external radiation from radioactive compounds, and reduce hazards from possible chronic vanadium and uranium metal poisoning. Most uranium ore occurs in rocks of high free silica content. Adequate dust control must be maintained by wet drilling, wetting muck piles, and good ventilation to reduce hazards of silicosis as well as control airborne radioactive materials. It should be mentioned that some mine water on the plateau contains high quantities of dissolved radon and its use in mining operations may result in an added source of radon in mine atmospheres.

On the basis of conducted experiments, the Division of Occupational Health, U. S. Public Health Service, suggests that for relatively nonextensive mines, at least 500 c.f.m. of fresh air be directed to a dead-end drift, or 1,000 c.f.m. where high concentrations of radon are encountered. In large stopes or rooms they suggest that at least 1,000 c.f.m. be maintained, or 2,000 c.f.m. in areas of high radon concentrations. They suggest that fresh air be delivered to within 30 feet of the working area and that means of supplying a minimum of 2,000 c.f.m. of fresh air be available at any mine even though not needed to meet the above requirements. As added precautions it has been suggested that the minimum velocity of 30 linear feet per minute be maintained in contaminated areas of large cross sections, that the mine atmosphere be changed every 4 minutes, and that ventilation equipment be started at least 30 minutes before entering the mine. A Colorado mine safety law states that the maximum allowable concentration for alpha emitting decay products of radon should not exceed 100 micro-microcuries per liter of air. A recently enacted New Mexico mine safety law, using the same guide for maximum concentration of radiation, states that mechanical ventilation methods capable of producing 500 c.f.m. of air per man at each working face must be installed at every mine where radon gas is present.

15/ Ayer, Howard E., Control of Radon and its Daughters in Mines by Ventilation: U. S. Public Health Service, U. S. Atomic Energy Commission AECO-2858, Mar. 15, 1954.

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Diesel-powered locomotives, trucks, shovels, caterpillar-tractors, and loaders can be used with safety in underground uranium mines if such equipment is properly designed and maintained in good repair and if the exhaust gases are sufficiently diluted. The Federal Bureau of Mines recommends that the air-fuel ratio for diesel-powered equipment be maintained at 20:1. Exhaust-gas conditioners must be maintained properly to lower the temperature of exhaust gas, absorb some of the toxic gases, and remove most of the smoke and irritating constituents. The remaining contaminants should be diluted by mixing them with larger amounts of clean air before discharging them into the atmosphere. The volume of ventilating air must be sufficient to dilute the toxic gases below the maximum limits regarded as safe, and the velocity of the air currents must be sufficient to eliminate accumulated gas pockets. Natural ventilation may provide the required air movement in the main air courses if the mine openings are sufficient in number and the mine workings have large cross-sectional areas, however, positive ventilation should be used in all mines where diesel-powered equipment is used underground to insure year-round safety. Provisions should be made to ventilate dead-end workings.16/ A Colorado mine safety law states that there should be a minimum of 75 c.f.m. of fresh air for each brake horsepower of diesel-powered engines used underground. Virtually normal air must be maintained in the mine workings if diesel-powered equipment is to operate efficiently and safely.

State mine safety laws vary with respect to maximum concentration of some toxic gases in mine atmosphere. Based on standards accepted by the Federal Bureau of Mines, maximum safe concentrations of various gases in an underground atmosphere are:17/

Carbon dioxide (CO_2) - not more than 0.5 percent by volume.
Carbon monoxide (CO) - not more than 0.01 percent by volume.
Oxides of nitrogen (NO and NO_2) - not more than 0.0025 percent by volume.
Aldehydes (as equivalent formaldehyde) - not to exceed 10 p.p.m.

The same reference suggests a minimum concentration of 19.5 percent oxygen by volume.

Conditions needed for the natural flow of air through the main or general ventilation system are a sufficient year-round temperature difference between surface and underground and an appreciable difference in elevation between intake and exhaust openings. Natural ventilation cannot be depended upon to provide enough year-round air flow to control contaminants in the uranium mines on the plateau. This is because temperature differences between underground and surface is too slight during many months of the year, and in mines with two or more openings, the difference in elevation between the openings usually is not enough to cause the required volume of air to flow through the workings. In mines with only one opening, limited movement of convection air currents does not provide adequate ventilation.

State mine safety laws stipulate the number of mine openings and relative conditions required for ventilation and escapeways. Mechanical ventilation may be induced by a blower or exhaust fan installed at the collar or portal of a second mine opening and, with proper control, the air currents can be coursed to the

16/ Harrington, D., and East, J. H., Jr., Diesel Equipment in Underground Mining: Bureau of Mines, Inf. Circ. 7406, 1947, 87 pp.
17/ Elliott, M. A., and James, R. S., The Development of Permissible Requirements for Safe Underground Diesel Haulage: Bureau of Mines Inf. Circ. 7673, 1953, 12 pp.

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working areas (see fig. 34). Stoppings, ventilation doors, or small auxiliary-type fans and ventilation tubing can be used to control and direct the ventilating air. General mine air contamination may be lessened and ventilation requirements decreased if mined-out areas are sealed off. Typical of many mines on the plateau, resistance to air currents is increased by obstructions, the erratic horizontal and vertical extent of the workings, and the differences in cross-sectional area of the workings. Control of air currents is difficult when there are many dead-end working areas and where air currents are short-circuited through interconnected workings.

Some mine operators have provided secondary ventilation openings with 10- to 18-inch churn-drill holes drilled from the surface to intersect the workings near the mining faces. With small exhaust fans installed at their collars, radon gas and other contaminants are exhausted directly from these areas rather than being coursed throughout the mine (see fig. 35). Although this is a relatively cheap method of providing a secondary ventilation opening, the capacity of these holes is limited. The adequacy of this method depends upon the capacity of the ventilating system relative to the underground requirements for fresh air. The capacity depends on the number, size, length, position, and resistance of the holes, mine resistance, and capacity of the fans used. The requirements depend on the number of men working and the amount of air impurities such as radioactive dust and gases, diesel engine exhaust gases, and dust and gases from mining operations.

A new method of providing a secondary mine opening, serving the dual purpose of a ventilation opening and as an escapeway, has recently come into use on the plateau. Thirty-six-inch churn-drill holes are drilled from the surface to connect with the mine workings. The reported contract drilling price is $36.00 per foot with an additional charge to cover the expense of moving equipment to the drill-hole site when the drilling depth is relatively shallow. Contract cost for installing sheet-steel lining and steel ladderways and landings is reported as an additional $10.00 per foot.

The working areas in mines developed by a single adit or shaft, can be ventilated by surface fans installed near the portal or collar, which direct air to the working areas by either metal or flexible ventilation tubing. Booster fans should be installed to maintain the required ventilation where length of tubing lowers efficiency. A Colorado mine safety law requires booster fan installation in ventilation tubing at intervals not to exceed 500 feet.

SUMMARY

Uranium mining is a business venture, and, as in any business, the aim is maximum return on investment capital. A uranium deposit is ore only if it can be mined at a profit. Uranium deposits are exhaustible and therefore every operating mine is a wasting asset. Advance planning is invaluable in exploration, development, and mining. Competent and experienced personnel are necessary for planning and directing these operations.

Anyone who contemplates prospecting or exploration for uranium should avail himself of the published information on the geology relative to uranium deposits on the Colorado Plateau. Most of the surface exposures of formations known to be favorable have been prospected in this area. Although there are still vast areas near rims where exploratory drilling will be conducted, it is logical to assume that future exploration will be in areas progressively farther from exposures, at greater depth, and possibly in horizons not now known to be favorable. Risk becomes greater, and conservative planning, to secure the most information for the least

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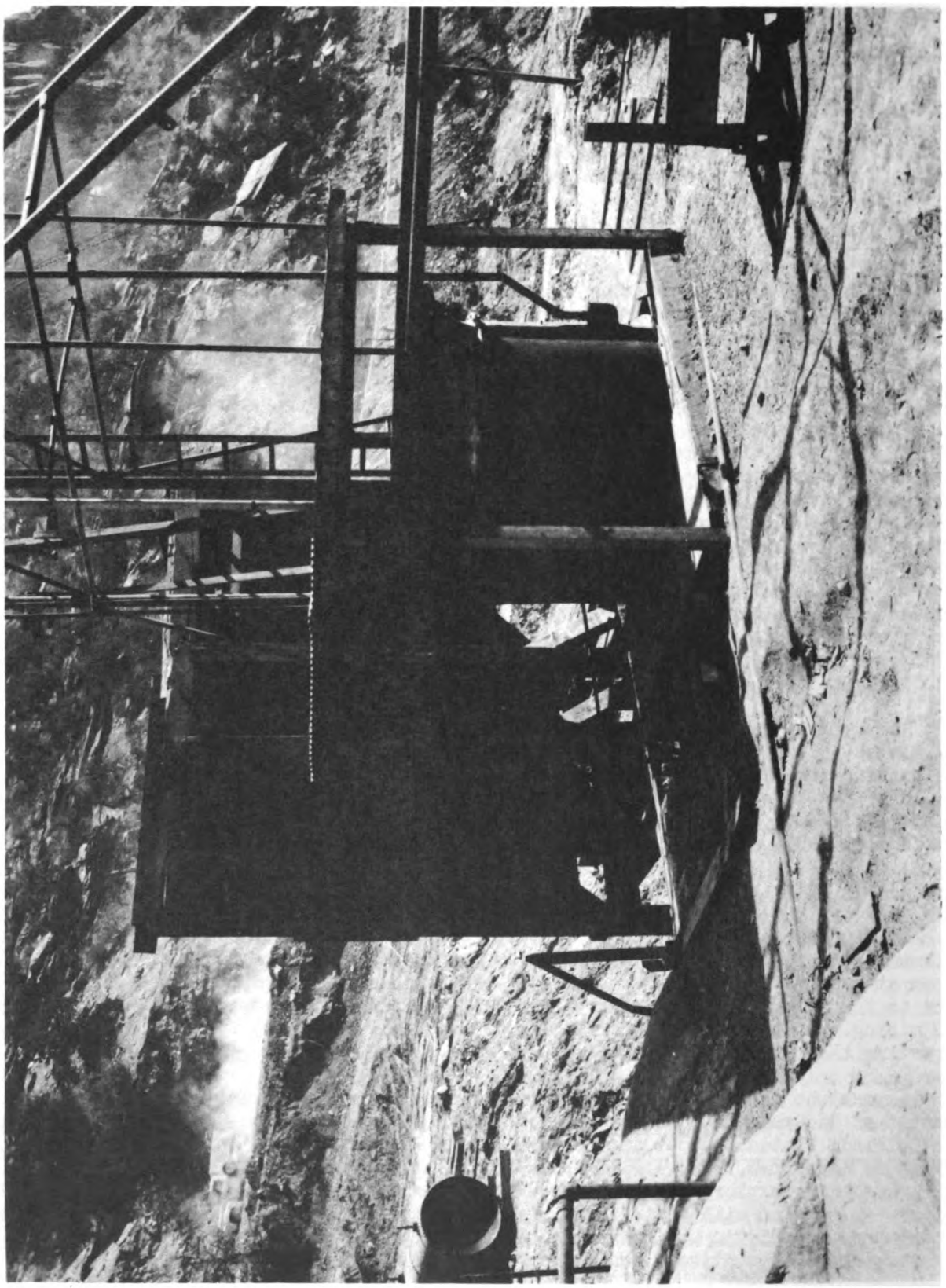

Figure 34. - A 100,000 c.f.m. axial-flow surface exhaust fan installation.

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Figure 35. - Small, surface ventilation fan installation at collar of drill-hole.

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cost, together with proper interpretation and evaluation becomes increasingly important.

The development plan depends on and must necessarily fit the physical conditions of the ore body and topography. It is important to take the utmost advantage of those conditions that are favorable. The more information obtained by exploratory drilling, the more intelligently development can be planned. The optimum development method is one that will permit complete extraction of the ore at the least cost. A development entry should provide the cheapest method of contacting the ore body, and should be one that will permit efficient mining at the planned rate of production. The development plan of underground levels depends upon the characteristics of the ore body but may be modified to permit the use of a particular type of haulage equipment. Advance planning is essential where a systematic method of retreat is necessary for extraction of ore pillars.

Careful consideration should be given to proved mining techniques and the use of mining equipment standardized by the mining industry. Care should be taken to control the grade of ore mined since the Atomic Energy Commission and privately operated mills pay for pounds of U_3O_8 rather than tons of rock.

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